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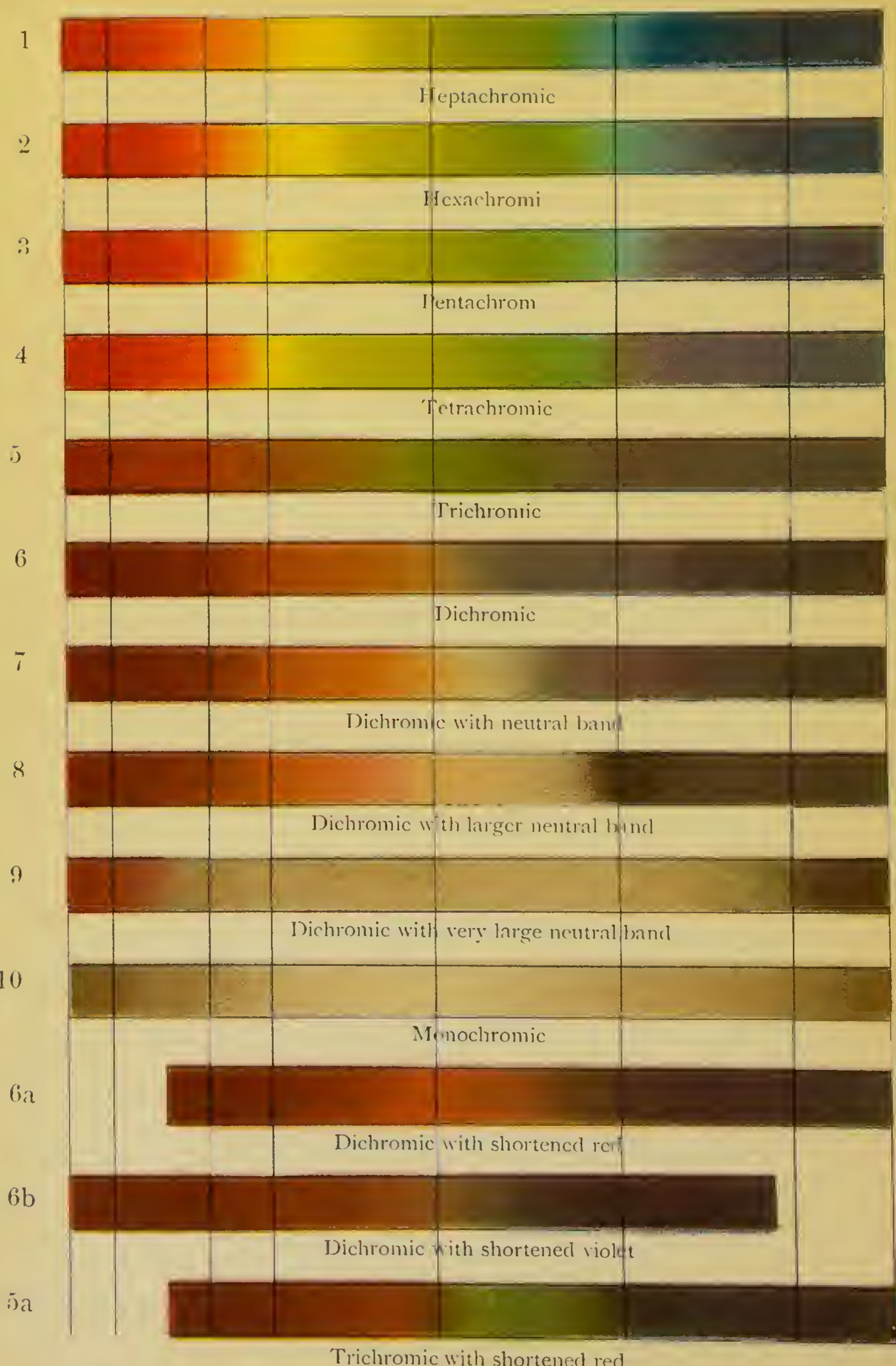
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Dichromic with larger neutral band
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Dichromic with very large neutral band
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Monochromic
6a
Dichromic with shortened red
6b
Dichromic with shortened violet
5a
Trichromic with shortened red

COLOUR-BLINDNESS

AND

COLOUR-PERCEPTION

BY

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"MEMORY AND ITS CULTIVATION,"

LATE MEMBER OF THE INTERNATIONAL CODE OF SIGNALS COMMITTEE, ETC.

SECOND EDITION

WITH THREE COLOURED PLATES

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PREFACE.

THE very favourable reception accorded to my book on "Memory" and papers on "Colour-blindness" has induced me to write this book for the benefit of those who may have to test for colour-blindness.

The theory of colour-perception which I have advanced in this book is an application of the theory of psycho-physical perception, described in my book on "Memory," to the phenomena of colour-blindness and colour-perception.

This book is essentially practical. The observations are based on the careful examination of 116 colour-blind persons and of all the recorded cases to which I could obtain access. I should be glad to hear from any colour-blind person concerning his views on colour, and the difficulties which he has encountered. I have obtained much valuable information from colour-blind persons relating to facts concerning their colour-perception which they have found inconsistent with the ordinarily accepted views.

If the theory which I have given in this book be not true, it must be very closely allied to the truth, as all my

theoretical predictions are verified by facts. In examining colour-blind persons, I avoided all leading questions, so that no bias should be given to them one way or the other. I have given a numerous series of cases which, even if the theory be not accepted, are definite facts of colour-blindness to which any future theory must conform.

The practical portion of this book is the outcome of the work which I did at the request of the Board of Trade.

I must here express my great indebtedness to the officials of the Marine Department of the Board of Trade, and especially to the late Mr. Gray, for the assistance which they have afforded me in making my investigations. Mr. Gray took the greatest interest in colour-blindness, and spared no trouble to obtain efficient tests. It seems remarkable to me that criticism has been almost confined to the colour-tests of the Board of Trade, whilst those used by the Navy and Railway companies, which are incomparably less efficient, have scarcely been noticed.

PREFACE TO SECOND EDITION

I HAD intended to reply to any adverse criticism, but there has never been any worthy of the name. Those readers who are acquainted with the subject of colour-vision and colour-blindness will remember that in not a single instance has one of my opponents given any specific fact or shown that one of my deductions was wrong. The criticism has always been vague and general or absolutely denying some easily ascertained fact. In many cases my opponent has a few years afterwards brought out the same fact himself without mentioning my name. It will be noticed that the whole of the original facts in this book were discovered by deduction, that is, I looked for them because of the theory and found that they existed. I have been endeavouring during the last twenty years to find some fact which was not in accordance with the theory. There has been need for very little alteration in the body of the work; additional matter I have added as an Appendix.

The reader who has not perused the first edition of this book will probably remark that there is very little in it differing from modern views on the science of colour and colour-blindness. This was not the case twenty years ago; there was scarcely a point on which I was in

agreement. The general view has, however, steadily and almost imperceptibly changed, and my own theories and facts are continually described to me under the impression that they are the older views. In fact, not long back I received a letter referring to an article I had written in the *British Medical Journal* inquiring why I had not stated that my views were in general agreement with modern science. It would indeed be quite easy to support my theory entirely from the work of others who have arrived at similar conclusions to my own.

There is one point to which I must allude in the interests of general science, and that is the extreme difficulty which exists in this country in obtaining an opportunity of demonstrating new facts (even of the simplest character), or a fair discussion of new hypotheses. There are certain men, unfortunately, belonging to official science who, whilst ready to condemn anything new in the most emphatic and arrogant manner, absolutely refuse to examine the facts, or to give a reason for their condemnation. This type is particularly common at Cambridge. I must therefore express my great indebtedness to Sir Lauder Brunton, Sir William Ramsay, the late Sir Michael Foster, Sir Victor Horsley, Dr. F. W. Mott, the late Dr. H. Hicks, Profs. Waller, Halliburton, Starling, Gotch, Haldane, Mr. Devereux Marshall, and Mr. Doyne, who have endeavoured and finally succeeded in obtaining a fair hearing for me. I am also indebted to the late Dr. W. Pole and Sir J. J. Thomson for the observations which they have made for me of their own cases.

The reader will be surprised when I tell him that it has taken me twenty years to obtain official recognition of such simple facts as that certain colour-blind men can pass the wool test, and that when a definite portion of the spectrum is isolated it appears monochromatic. I hope that the time will soon arrive when an opponent, at a meeting of scientific men, whose only remark is, 'Who are you to criticise the greatest men of all time?' will be promptly called to order by the president and told to state definite facts. Unfortunately, the above remark is very telling with almost any audience as it appeals to their self-esteem. Whenever I have challenged my opponent to give some definite fact, no matter whether the discussion has taken place at a meeting or in a journal, he has promptly subsided. The reader who is interested in this question should read the correspondence and editorial in the *British Medical Journal*, Nov. 23, 1907—March 1908.

I hope, therefore, that the reader who may be inclined to doubt any of the statements in this book will test for himself whether they be true or not.

What we want to get at is the truth. Never mind who finds it out.

This edition contains much additional evidence in favour of the solution of the problem of vision which I first mentioned in the previous edition. The last links in the chain I have only recently discovered. The theory not only explains the facts, but explains them according to photochemical laws. Though I have taken careful measurements in every case I have rarely given

curves and tables, both on account of the space at my disposal and because the book is not intended entirely for those occupied with pure science. I have also had to omit much relevant matter for the same reasons.

Those who wish to judge the matter fairly should read the original papers of those who have taken a different view, as, for instance, the accurate and beautiful work of Kühne. The facts given are in favour of the view expressed in this book. It must be remembered that Kühne had no opportunity of considering the matter according to this hypothesis, or in the light of the facts which have been discovered during the last thirty-two years.

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Hendon Grove,
Hendon, N.W.

CONTENTS.

COLOUR-BLINDNESS AND COLOUR-PERCEPTION.

CHAPTER I.

HISTORICAL.

The first definite step towards an appreciation of the science of colour was made by Newton, by his researches in optics and his demonstration of the compound character of the sun's light. Kepler was the first to discover the compound nature of solar light, but comparatively little attention was paid to his observations. The experiments of Newton attracted more notice, and his theories were accepted by the scientific men of his time.

Newton was of opinion that white light is made up of seven different colours: red, orange, yellow, green, blue, indigo and violet, each differing in refrangibility.

Brewster was of opinion that there are three different colours in the spectrum—red, yellow, and blue. He believed that the simple spectrum is composed of three different spectra — red, yellow, and blue. Helmholtz pointed out, in a very able paper, the defects in Brewster's methods of experimenting, and, except with artists, this theory has been very generally rejected.

The first definite record we possess of a case of colour-blindness, is Huddart's account of the shoemaker Harris, in 1777. In 1794, Dalton described his own case. His attention was drawn to his affection by finding that the flower of the *Geranium zonale* was of a different colour by artificial light from that which it appeared to him by daylight. The flower was pink, and appeared to him sky-blue by day, and without a trace of blue by candle-light. His friends assured him that the colour of the flower was not materially altered when viewed by artificial light.

In 1810, Goethe * applied his theory of colours to colour-blindness. He believed that the affection was due to a defective perception of blue, and called it acyanoblepsia.

Seebeck † was the first to systematically classify the colour-blind, his observations being based on the examination of twelve cases. His method of examination consisted in letting the colour-blind classify about three hundred pieces of coloured paper. He also used pieces of coloured glass.

Szokalski, Purkinje, and Elie Wartman have also made classifications of the colour-blind.

Wilson was the first to point out the dangers of colour-blindness, though very little attention was paid to his remarks.

The only theories of importance are the Young-Helmholtz and the Hering theories of colour-perception. Nearly all the tests and papers on colour-blindness have been based on one or other of these theories, which will be dealt with fully in a later portion of this book.

* Goethe, "Farbenlehre," pp. 126–190.

† "Ueber den bei manchen Personen vorkommenden Mangel an Farbensinn," von A. Seebeck. Poggendorff's "Annalen der Physik und Chemi;" bd. xlii. (1837), n. 100, p. 177.

I will conclude this chapter by alluding to those, not previously mentioned, to whom we are chiefly indebted for a knowledge of colour-blindness and the dangers arising from this defect. It is hardly necessary for me to allude to the work of Holmgren, who, following in the footsteps of Wilson, has done so much to draw general attention to the subject. Amongst foreign contributors Stilling, Donders, Cohn, Phlüger, Joy Jeffries, Favre, Magnus, Burnett, v. Kries, Nagel, Hess, Landolt, and Hirschberg must be mentioned; and in England, Brewster, Herschell, Tyndall, Maxwell, Pole, Abney, Raleigh, Galton, Nettleship, Bickerton, Frost, and Hogg.

CHAPTER II.

THE PHYSICAL BASIS OF COLOUR.

Colour is a sensation, and not an unalterable physical quality of bodies. The same substance may vary in colour according to the conditions under which it is viewed. The rays of light which give rise to the sensation of colour, are unalterable, and it is the suppression or admixture of certain of these rays that gives rise to changes in the colour of an object. If we examine, with a prism, a beam of sunlight admitted through a slit in a shutter, we notice that the slit appears much broader than before, and variously coloured. This is due to the unequal refraction of the constituent rays of white light. A beam of sunlight, examined in this way, gives a continuous spectrum; but if we take precautions to prevent overlapping of the different rays, by using a very fine slit, and obtaining a very sharp and defined image of the spectrum, we see that it is not continuous, but subdivided by a number of fine black lines. These lines, which were first discovered by Wollaston, and twelve years later more fully described by Fraünhofer, are due to the absence in sunlight of the particular rays which would, when refracted, occupy this position. Fraünhofer marked out 576 of these lines, and named the principal of them after the letters of the alphabet. Light, according to Huyghens and Young, is

due to the undulations of a medium called the luminiferous ether which is assumed to pervade all space. There is no direct evidence of this ether, but the theory explains in such a complete manner all the various phenomena of light, that it is hardly possible to doubt its correctness.

There is considerable difference between the undulations of air in the production of sound, and those of the luminiferous ether giving rise to the sensation of light. In the former case the waves are waves of condensation and rarefaction; that is to say, the direction of the motion has the same direction as the sound. In the case of light, the wave motion is perpendicular to the path of the ray. The vibrations of a ray of light are in all azimuths, but the movement of the wave is in each case perpendicular to the path of the ray. Wave-motion may be admirably illustrated by throwing a stone into a pond. The stone will, for a short period of time, cause a depression in the surface of the water. On account of this depression the adjacent molecules of water will be raised above the horizontal level of the pond, and a wave will be started. The molecules forming this wave will then sink to the level of the pond and then below it, the adjacent molecules being influenced as in the first instance. In this way the wave will be propagated until either the bank is reached or the waves become too feeble to influence the molecules of water adjacent to them. It will be noticed that there is no real transmission of matter; thus, if there be a stick or leaf in the path of the wave, it will be raised with the wave, but left in the same spot after the wave has passed.

The following table * gives the length in inches of the undulations corresponding to the light at the principal dark lines of the spectrum :—

* Ganot's "Physics," p. 586.

Dark line.	Length of undulations in inches.
B	0·0000271
C	0·0000258
D_1	0·0000232
E	0·0000207
F	0·0000191
G	0·0000169
H_1	0·0000159

The following is a table of wave-lengths in tenth-meters, by Angstrom :—

A	7604	E	5269
B	6867	F	4861
C	6562	G	4307
D_2	5895	H_1	3968
D_1	5889	H_2	3933

The velocity of light is 300 million metres per second, or 300×10^{16} tenth-metres per second. The number of waves per second for any colour is therefore 300×10^{16} divided by its wave-length as above expressed. Proceeding in this manner we find approximately :—

For A, 395 millions of millions per second.
„ D, 510 „ „ „
„ H, 760 „ „ „

The respective vibrations for the rays at the ends of the spectrum are as follows. For the extreme red, 395 billions of vibrations per second. For the extreme violet, 763 billions of vibrations per second.

The rays of light which give rise to the sensation of red are also less refrangible than the remainder, the refrangibility increasing up to the violet.

From this it will be seen that a spectrum consists of an enormous number of rays of light arranged side by side, each differing from the others in wave-length and refrangibility.

Besides the rays of light which compose the visible

spectrum, there are two other sets of rays, which under ordinary circumstances are not visible to the naked eye. These are the heat-rays and the actinic rays. The former are of lower refrangibility and have a longer wave-length than the red rays; the latter possess greater refrangibility and a shorter wave-length than the violet rays.

Under certain circumstances these rays may be transmuted—that is, have their wave-length altered, and so be made visible. Professor G. G. Stokes has succeeded in converting the ultra-violet into rays of lower refrangibility, whilst Professor Tyndall has been able to convert the infra-red into rays of a higher degree of refrangibility. If the spectrum be looked at through a piece of cobalt glass, a bright crimson band will be seen below the red, whilst the presence of rays above the violet is demonstrated by fluorescence and other phenomena.

The most important point concerning the physical basis of colour is, that the rays of light giving rise to the sensation are arranged in a series in the spectrum, and that physically we are not cognisant of the limits of this series. We know that there are heat-rays and actinic rays because we have direct evidence of their existence, but we do not know where the light series commences or terminates. There may be rays considerably below the red which are performing useful work, and which cannot be brought under the direct evidence of the senses. In order that the reader may be able to follow the theory on which this book is based, it is essential that he should regard the spectrum as a portion of a physical series, the latter having no commencement, termination, or definite unit. The physical-light series, therefore, consists of rays having different wave-lengths. A unit in the physical series is represented by a single ray having a definite wave-length. The physical basis of colour is the light

which is reflected from or transmitted by a substance. Without these rays a substance will not only not be coloured, but appear black. For instance, if we look at a piece of ultramarine by the light of burning sodium it appears black. Without light we cannot have colour, and as the light of the sun is white, it must follow that something must be added to, or subtracted from, this light before colour can be produced. In the following chapters it will be shown why a certain combination of rays gives rise to the sensation of a certain colour. In this chapter it only remains for us to consider what changes in the series are capable of giving rise to *any* sensation of colour.

The following are the ways in which white light is altered so as to give rise to the sensation of colour.

1. Colours produced by Dispersion.—When colours are produced in this way, the white light is not altered in character. The constituent rays, on account of their unequal refrangibility, are spread out in the form of a series. This is called the dispersion of white light. The colours of the rainbow are good examples of colours produced by dispersion.

2. Colours produced by Absorption.—In the case of opaque bodies a certain number of rays of light are absorbed, and the remainder reflected, giving rise to a sensation of colour. In the case of transparent bodies, a certain number of rays are absorbed, and the remainder transmitted, giving rise to a sensation of colour.

This is the commonest way in which colours are produced; the colours of flowers and pigments of all kinds being due to this cause. When pigments are mixed the resulting colour is that which is reflected by both pigments. It is in this way that yellow and blue pigments, when mixed, make a green. The pigments used are not pure—that is to say, the yellow pigment reflects green as

well as yellow light, and the blue pigment reflects green as well as blue light. When the two are mixed, the whole of the light with the exception of the green is absorbed, and so the resulting colour is green. A very simple experiment will demonstrate this fact. If a piece of yellow and a piece of blue glass be taken and a white cloud viewed through the two it will appear green. The piece of yellow glass may then be subjected to spectroscopic analysis: it will be found to transmit in addition to the yellow rays the orange, green, and some of the red rays. The blue glass will be found to transmit, in addition to the blue rays, the violet, green, and a band of red at the extreme left of the spectrum. If the light transmitted by both glasses be now examined, it will be found to consist almost entirely of the green rays, hence the green colour of the transmitted light.

3. Colours produced by Interference.—The production of colour by interference is admirably explained by the wave theory of light. The following explanation will show how these colours are produced. If we throw a stone into a pond we shall start a series of waves. If, before these waves have subsided, we throw another stone into the pond, in a different place, we shall set up another series of waves. The following phenomena will then be noticed. Where the waves meet so that the crest of one wave corresponds to the crest of another wave, the two will combine, giving rise to a wave twice the size of either. If, however, the waves meet so that the crest of one wave will correspond to the trough of another, the water will remain calm and undisturbed. The light-waves may interfere in a similar manner. When the crests of the light waves correspond, both are reinforced, and the light becomes brighter. When the crest of one light wave corresponds to the trough of another of similar wave-

length, both are annihilated, and darkness is produced. These phenomena are admirably illustrated by Newton's rings. The rings are made by pressing a convex lens on a piece of plane glass. Newton's rings, viewed by the monochromatic sodium light, appear alternately light and dark. Darkness will only be produced with monochromatic light. When ordinary daylight is used, the rings appear coloured, because this light being composed of rays of different wave-lengths, only a portion of the light will be destroyed, and so colour is produced. The colours produced by diffraction, thin plates, and polarization are due to interference.

The above are the commonest ways in which colour is produced, but colour may be produced by alteration in wave-length, as in fluorescence, or by light which has been absorbed being given out again, as in phosphorescence.

It is therefore evident that in the absence of light colour is not produced, and that colours having a similar appearance to the normal-sighted may have a very different composition, as far as the physical structure of the colour is concerned. When I speak of the physical structure of a colour, I mean the composition of the light which is reflected from or transmitted by a coloured body.

If we take a small portion of the spectrum produced by a good spectroscope we shall obtain a band of apparently monochromatic light. If shutters be used to the spectroscope we shall not be able to say which is the red and which the violet side of the spectrum. By this means we obtain the purest possible colour. As has been previously explained, the band is really made up of numerous waves of light which differ from each other in wave-length and refrangibility. For comparison let us take twelve yellow bodies, choosing those which are as nearly as possible similar in every respect. Then we find that the same

colour may be produced in an almost innumerable number of ways. Let us first deal with solar light. If this falls upon a body and the particles of that body absorb some of the blue rays it will appear yellow. It will therefore be seen that the composition of this yellow consists of red, orange, yellow, green, a few blue, and the violet rays of the spectrum. Gaslight is a good example of yellow light of the above composition. It is rare to find a yellow body which reflects only the yellow rays of the spectrum. Most yellow bodies reflect the orange rays and some of the red and green. We may even have a yellow which contains no yellow rays at all but is only a mixture of red and green waves.

CHAPTER III.

THE THEORY OF PSYCHO-PHYSICAL PERCEPTION.

THE theory of psycho-physical perception was the necessary sequence of certain views which I have taken of the nervous system. These views differ very considerably from the ordinarily accepted theories, and, as far as I am aware, are entirely my own.

Most psychologists agree in assuming that the mind is made up of a number of faculties. The phrenologists deserve the credit of having classified these faculties and their classification is a fairly good one. I may say that with phrenology, as expounded by the phrenologists, I totally disagree.

The name applied to these faculties is of secondary importance. When we see that one man is able to perform the most abstruse calculations, whilst another man is hardly able to master the multiplication table, it is evident that there is a difference between the two, which may be admirably expressed by saying that the faculty of calculation is large in the first man and small in the second. We have very little evidence to show where the faculties are situated, whether they are spread over a considerable portion of the brain, or whether they are confined to certain convolutions. I am inclined to hold the latter opinion.

The following are the conclusions which I have come to with regard to the perception of sensations :—

1. That in the cerebrum there are definite centres having the function of conveying to the mind information respecting impressions which have been conveyed from the external senses.

2. That the seat of memory is situated at a lower portion of the brain than the perceptive centre—that is, at a point between the perceptive centre and sense organ, probably in the optic thalami.

3. That all portions of an impression of sight are connected in the seat of memory; that is to say, the impression is not divided, but the whole exists as a faint impression of that which was at first received. Thus, when we look at a landscape a definite impression is conveyed to the mind, and this impression is remembered as a whole. Different portions of an impression may be accentuated according to the relative size of the perceptive centres for each class of impressions.

4. That the act of perception is the perception of differences in a physical series, the mind as a whole being made aware of these differences through definite perceptive centres.

5. That the mind is only conscious of the impressions in the seat of memory through the perceptive centres.

6. That defective size of a perceptive centre will prevent the act of perception from being perfectly performed; that is to say, fewer points of difference are evident in the physical series.

For the arguments and facts in support of the above views I must refer the reader to my book on "Memory."

We can only have cognizance of the external world as our senses and faculties inform us of its existence. Any defect, either in the sense-organ or perceptive centre, by preventing the perception of certain classes of sensations, has the same effect as if the physical stimuli

giving rise to the sensations did not exist. It is impossible to explain to a man who has been born blind what sight is; he is unable to appreciate what such a sense can be, and so does not feel the want of it in the same way as a man who has once been possessed of sight.

The fact that defects in the estimation of sensations may be due to some defect in the brain, has been very generally overlooked by those who have been considered authorities. Physicists, as a class, are too much inclined to overlook the personal element when making their investigations. They appear to take for granted that the perceptions of others are similar to those experienced by themselves.

In the perception of a sensation there are the following factors to be taken into consideration:—

1. The physical stimulus.

2. The sense-organ receiving this stimulus.

3. The nerves conveying the effects of the stimulus.

4. The centre of memory receiving the whole impression.

5. The perceptive centres conveying to the mind information concerning individual portions of the impression.

Therefore imperfect perception may be due to a defect in any one or more of the above five factors.

What takes place in normal perception?

Let us take, for example, the perception of size. To illustrate this we must have a physical series. Let us suppose that we have a series of spheres, differing in size from the smallest object capable of being perceived by the naked eye to a very large sphere. Each unit of this series should differ from the adjacent units in a very slight degree. This will approximately represent a physical series. The appearance of this series to any person will be the psycho-physical series for that person. A psycho-

physical series is therefore a physical series as it appears to the mind. The series will appear as if it were divided into a number of units, each containing a number of spheres of apparently the same size. It will then be found that the person who is able to distinguish most easily minute differences of size, will be able to see more of these units than other persons; that is to say, he will not put so many of the physical units together, as being exactly alike, as another person would. We then find that people differ very much in the number of units which they put together as exactly alike. So we are able to make definite classes, varying from those who are able to perceive very minute differences of size to those who can only distinguish (by the eye) large and small objects, and are therefore size-blind. It will be noticed that individuals will mark out points in the series where the difference between the units is so distinct that they would have noticed it if these units had been shown separately, and not in the form of a series; others in which they are able to notice a difference because the adjacent units are present for comparison; and others in which no difference can be detected, even with the most careful comparison. These latter will be included in an absolute psycho-physical unit. But the former class will form an approximate psycho-physical unit—that is, a psycho-physical unit containing physical units which are not easily distinguished from each other, and are so much alike as to be put in the same class and called by the same name. These approximate psycho-physical units are the most important, and they are the ones to which definite names are given. As the size of the absolute is proportional to that of the approximate psycho-physical units, the latter are the only ones which it is necessary to ascertain. Thus, if each of the absolute psycho-physical units of a series contain

more physical units than the normal number, it must follow that the approximate psycho-physical units will be fewer, as the length of the series remains the same.

This outline of the theory having been given, we can discuss it in detail under the following heads :—

1. A Physical Series.—Before we can have a psycho-physical series, we must have a physical series. Physical series agree in their ill-defined character. For instance, let us consider a time series. It is impossible to conceive how there could be a commencement to time, or that time can ever end, or that we can conceive a portion of time, however small, which cannot be subdivided ; thus the portion of time which light takes to pass through the space of an inch can be divided into millionths.

Again, let us consider a position series. This may be illustrated with a compass. It is obvious that the circle representing definite positions may be subdivided to any extent. Innumerable degrees can be made between the points of the compass, as one passes by imperceptible gradations into another ; thus the space between N. and N.W. could be subdivided any number of times, the circumference being, if necessary, enlarged.

With regard to a heat series, we do not know what is the lowest or highest possible temperature, and it is evident that there are innumerable gradations from one degree to another.

It is the same with a sound series, which appears at first sight to form an exception as far as the indefinite character of the units are concerned. It is evident that we do not know what is the lowest or highest possible number of vibrations which bodies may be put into, but it appears that there are definite units—that is to say, so many vibrations per second. But the second itself is quite an arbitrary standard of time, and it is quite possible, and

appears to me probable, that there are innumerable degrees between, say, 14 vibrations per second and 15 vibrations per second; for instance, $14\frac{1}{16}$, $14\frac{1}{17}$, $14\frac{1}{18}$, etc., vibrations per second. These may exist, but we are not able to perceive them. An illustration will make this clear. It is evident that a second is quite an arbitrary division of time; we might with equal propriety have divided the minute into one hundred, eighty, or fifty equal parts. We can range sounds in a series from those which are produced by 8 vibrations per second, to those which are produced by 36,500 vibrations per second. Let us then change the standard of time, and suppose that there are only 59 seconds in a minute instead of 60, and then estimate the vibrations per second according to this scale of time. It is evident that nearly every one of the units will have fractional vibrations per second. It is probable that in some hundreds of apparently similar sounds that there are not two alike, simply considering the vibrations per second. For instance, supposing we take one hundred sounds all apparently produced by bodies vibrating 75 times to the second, as ascertained by the most accurate apparatus obtainable. There is nothing to show that one body is not vibrating $75\frac{1}{1365}$ times per second, another $75\frac{19}{365}$ times per second, and so on.

Then we may have a form series, the units ranging from a perfectly straight line to the greatest possible curve.

In the same way we may have a weight series. It is impossible to conceive a weight which cannot be diminished, and it is impossible to conceive a weight which could not be increased. Also it is impossible to conceive a unit of weight which could not be subdivided.

It is the same with all other physical stimuli which are capable of giving rise to definite sensations. These

may be ranged in series, each of which has no definite commencement, no definite termination, and no definite unit.

For the purposes of physics, it is necessary to assume a physical unit, though in reality we are not able to define or obtain one. As long as these *approximate* physical units each contain a similar number of the hypothetical physical units, they will be adequate for purposes of comparison. If we take one tenth of a second as representing an approximate physical time unit, it is evident that we could make a series of an hour which would then consist of $60 \times 60 \times 10 = 36{,}000$ equal portions, each of which would contain an equal number of the hypothetical time units.

For the purposes of this book, I shall use the term *physical unit* as meaning the smallest conceivable portion of a physical series.

2. A Psycho-physical Series.—By a psycho-physical series, I mean a physical series as it appears to the mind. A psycho-physical series is a sensation which is referred to external objects. It is obvious that the product of the physical stimulus may be considerably altered before it reaches the mind.

The chief points in which a psycho-physical series differs from a physical series are, that it has a definite commencement, a definite termination, and consists of certain definite units. The limitation of the series is probably due to the external sensory apparatus, and any unit of a physical series not coming within the defined range is not perceived. A high note which is heard distinctly by one person, may be quite inaudible to another, and therefore he can form no opinion respecting its qualities. It is the same with the sense of smell. Professor Ramsay informs me that he has met with many persons who are unable to distinguish

that hydrocyanic acid has any odour whatever, whilst they are able to recognize other odoriferous bodies. It is obvious that if this condition were general, prussic acid would be said to be odourless. Therefore, the definite standard length of a psycho-physical series having been found for the majority of persons, any increase in this length for any individual will be a gain, and any decrease a loss for the person examined. When the psycho-physical series is shortened, the physical stimuli occupying the shortened portion will not be perceived, and the same result will be produced as if the physical stimuli did not exist.

The psycho-physical perception of colour will be considered in the next chapter. Unfortunately we cannot form series of other physical stimuli in the same way that we can with the rays of light, and therefore the study of the psycho-physical perception of these stimuli is attended with as much difficulty as the study of colour without the aid of the spectrum. Taking, for instance, odours, we are unable to range these in a series, though a good deal of light has been thrown upon the subject by Professor Ramsay, who suggests that a series might be formed in accordance with the molecular weight of the odoriferous body.

3. An Absolute Psycho-physical Unit.—The absolute psycho-physical units are the basis of every psycho-physical series. When a person has succeeded in obtaining a match, which to him appears perfect, it is evident that he has brought both stimuli within one of his absolute psycho-physical units, because all physical stimuli included in one of these units are regarded as identical. When a violin is tuned to the piano the following takes place. The A string of the violin is tuned until it is vibrating in harmony with a certain A of the piano. When a person

has succeeded in getting the two strings to vibrate in apparently perfect unison, it is evident that he has brought the two into one of his absolute psycho-physical units.

A musician with a more accurate ear, to use the common expression, would probably not be satisfied with the result. Again, a person with no ear for music, to use the ordinary expression, would be perfectly satisfied with a match which was markedly incorrect to most persons. A person who could not distinguish any difference in sound between the bass and treble notes—and I have met with such cases,—would be perfectly satisfied with any match whatever. The perception of weight could be ascertained by giving a number of persons a series of weights, and telling them to pick out those which are identical. To sum up, a perfect match indicates that the physical stimuli are included in an absolute psycho-physical unit.

4. An Approximate Psycho-physical Unit.—An approximate psycho-physical unit contains physical units which appear to be nearly alike. A difference can be distinguished between different portions of an approximate psycho-physical unit; but it is a slight difference. An approximate psycho-physical unit may be defined as a portion of a psycho-physical series containing absolute psycho-physical units the similarity between which is greater than the dissimilarity. A few examples, taken from the sense of taste, will make this clear. All physical stimuli which could be correctly defined by the word "sweet" would come within one approximate psycho-physical unit. There are many varieties of sweetness apart from the intensity of the sensation; thus sugar, honey, glycerine, and saccharin have each a particular characteristic sweetness, which would enable them to be distinguished from each other. If portions of the same liquid were sweetened with the

above four substances, it would be evident enough on tasting one of these portions that it was sweet, but it would not be so evident which of the four substances had been used. On tasting successively the four liquids, the sweetening agent used for each would be evident. When we have obtained two mixtures which apparently taste exactly alike when compared very carefully, the physical stimuli are included in an absolute psycho-physical unit. An approximate psycho-physical unit can be recognized without comparison; thus it is not necessary to taste an acid substance to find out whether another substance is sweet or not. The approximate psycho-physical units in a series are comparatively few.

5. The Points of Greatest Difference in a Physical Series.—As an example of the points of difference in a series in which the physical units are apparently equal, we can take the period of one hour as representing a portion of a physical series, and one-tenth of a second as a period representing an approximate physical unit. It is evident that the two points of greatest difference in the series are the first one-tenth second, and the last one-tenth second. The third point of greatest difference will be the half-hour. There will be two fourth points of difference; namely, the quarter past the hour, and the quarter to the hour. The next points of difference will be four in number, and the first will be midway between the starting-point and the quarter past.

It is the same with all physical series, the units of which differ by an equal amount. If we take a weight series, the commencement being one grain, and the termination one pound, it is evident that these are the two points of greatest difference. The next point of difference will be the half-pound, then the quarter and three-quarters of a pound weights, and so on.

But we can have a series in which the physical units are not equal; thus we can take a sound series in which the units differ from those which are produced by 8 vibrations per second, to those which are produced by 36,500 vibrations per second. It is obvious that a sound produced by 8 vibrations per second differs more from one produced by 9 vibrations per second, than a sound produced by 1000 vibrations per second differs from one produced by 1001 vibrations per second. But we can, with the aid of fractional vibrations per second, make the units differ to an equal extent, and then the points of difference will be as before.

6. The Points of Greatest Difference in a Psycho-physical Series.—We must first divide the whole physical series into psycho-physical units; for, as no difference can be made out between the physical units composing an absolute psycho-physical unit, they must be regarded as identical. The first effect of this is that the two points of greatest difference in a psycho-physical series are not necessarily the commencement and termination of the physical series. Any two physical units contained in the two terminal absolute psycho-physical units might be compared. For the sake of convenience, both the absolute and approximate psycho-physical units will be considered to be represented by the central point of each unit, because the appearance of the unit would be in no way changed if physical units similar to this centre one were substituted for the others in an absolute psycho-physical unit, and very little in the case of an approximate psycho-physical unit. In considering the points of difference in a psycho-physical series, it is necessary to take into consideration the effect which the physical stimuli have upon the sense organ towards the termination of the series. Thus in the case of sounds, a very high note, which was only

just perceived, would not form such a marked contrast to a bass note as one which was lower in the scale, and perceived more decidedly.

Another point which has to be taken into consideration in a psycho-physical series is the relative difference between the physical units; thus, there is as much difference between a weight of fifty-nine grains and one of sixty grains as there is between a weight of one grain and one of two grains; but it is evident that in the first case very few persons would perceive the difference, in the second case nearly every one would. The mind takes account of proportional difference much more than it does of real difference. The absolute psycho-physical units when seen alone are distinguished with difficulty from other absolute psycho-physical units occupying a position adjacent to them in the series, and so in practice the approximate psycho-physical units are the only ones which receive definite names.

To look at the subject from a practical point of view, it will be sufficient to remember that the theory is a theory of perception of difference. We can illustrate this in a practical manner with the discs to which I have previously alluded. It is obvious that the discs presenting the most marked contrast when compared, are the two at the ends of the series. It is evident that if the difference between the discs be slight, these are the only two which will be distinguished with certainty. The next disc presenting a marked contrast to the other two will be that in the centre of the series. Having obtained these three points, we can easily see how the series might be enlarged, but in any series these three points will remain unchanged, and will constitute the primary points of difference of the series. It is evident, therefore, that if a person be able to see four points of difference the series will not be divided

into four equal portions, because the members of the series at the ends and the middle will still remain the points of greatest contrast. Where, then, will be the fourth point of difference? It is evident that if the members of the series differ in a proportional degree, then the fourth and fifth points of difference will appear at the same time, and occupy a position midway between the ends and the middle of the series. If, however, the members of the series do not differ in a proportional manner, the fourth will appear before the fifth point of difference.

In illustration of this I will take the example of weight to which I have previously alluded. Let the physical series be represented by a series of weights from one grain to one pound. It is evident that the three points of greatest difference are physically and psycho-physically the grain, the pound, and the half-pound. Now comes a contrast between the points of difference in a physical series and the points of difference in a psycho-physical series. In the physical series, the two next points of difference appear together, and are the quarter-pound and three-quarter-pound weights; but this is not the case in the psycho-physical series. In the psycho-physical series the fourth point of difference is the quarter-pound weight, the fifth the three-quarter-pound weight. The reason of this is, that the proportional difference between a grain and a half-pound is greater than that between a half-pound and a pound. The half-pound is 240 times as heavy as the grain, whereas the pound is only twice as heavy as the half-pound. The sixth point of difference will appear on the grain side of the series; that is, there will be two points of difference between the grain and the half-pound instead of one. The seventh point of difference will appear on the half-pound side of the second half of the series, there being two points of difference between the half-pound and

the pound instead of one. The series may be increased indefinitely, additional points of difference being put first on the grain side of the series then on the corresponding half of the other side. It is evident that, however much the series may be enlarged, the primary points of difference will remain unaltered, because they always must be points of greater difference than any that can be perceived subsequently. Thus, however numerous the units in a psycho-physical weight series are, the two points of greatest difference must be the grain and the pound, the three points of greatest difference the grain, pound, and half-pound, and so on.

7. Effects of Defective Length of Psycho-physical Series. —The above is written to show the variations which we may expect in the perception of individuals when the length of the psycho-physical series is the same in each. But the series is not necessarily of the same length in each, and then other defects of perception will be produced. It is a well-known fact that persons differ very considerably in the height of the notes which they are able to hear. One person may hear a note which is more than an octave higher than that heard by another. Similar conditions are found with regard to low notes. It must be remarked that the note produces no effect whatever upon the person who is unable to hear it. As far as he is concerned it is non-existent. The following, given in the *Medical Press*, April 2, 1890, is an extreme example of this condition. The writer, referring to the late Mr. Cowles, an American journalist, says—

"It is stated that it was not until Mr. Cowles was twenty-five years of age that he became perfectly cognizant of his defect. Up to this time he treated all he read about the songs of birds as nothing more or less than poetical fiction. To him birds were perfectly mute; and

he was perfectly deaf to the shrillest and highest notes of the piano, fife, or other musical instruments. At length, after considerable pains, he was convinced that he laboured under some physical defect of hearing. When put to the test in a room where a large number of canary birds were singing very loudly, he declared he could not hear the slightest sound even when placed close to their cages. Moreover, it was found that all the sibilant sounds of the human voice were equally inaudible. The consequence was, he, like the deaf-mute, never used them in his conversation. Curiously enough, in all other respects his hearing was not only perfect, but somewhat acute."

It is therefore obvious that when a psycho-physical series is shortened relatively to that of other persons, the physical units included in the shortened portion are not perceived at all, and are practically non-existent. It is therefore impossible for a person to form any opinion with regard to their qualities, and in any mixture in which these physical units form part of the exciting stimuli they will have to be subtracted before the result can be obtained.

When the length of a psycho-physical series is different from that of the majority of persons, either shorter or longer, the centres of the different units will not correspond for both classes of persons. For instance, if one end of a series be shortened for any person, the third point of difference will be situated at a point rather nearer the other end of the series than it will be for those whose series is not shortened.

8. A Psycho-physical Impression as a Whole.—In the foregoing pages I have described the psycho-physical perception of a series. The result of this is that we have obtained the units of perception. It now only remains to show how these units are combined so as to make up an

impression as ordinarily perceived. In this book it is not my intention to show how many phenomena psycho-physical perception will explain, but only that it will explain the phenomena of colour-perception. I shall therefore confine myself to impressions of sight. Impressions of sight may be divided into four sets—those of *colour, form, size,* and *shade.* A psycho-physical impression as a whole is made up of the contiguous association of psycho-physical units; thus there will be the units of colour, form, size and shade. It will be seen that one set of impressions cannot be absolutely taken away from the others.

An impression of sight may be represented by a coloured photograph. We know that most persons see six definite colours. Let us suppose that most persons also see six definite varieties of form, size, and shade. As I have shown in the preceding pages, each psycho-physical unit might be represented by the physical unit occupying a position in the series corresponding to the centre of the psycho-physical unit. Then, from the photograph, we might construct a series of pictures which would approximately represent different varieties of psycho-physical perception. In the case of the normal-sighted we should construct a picture in which six different colours, six different form-units, six different size-units, and six different shade-units were used. In the case of diminished colour-perception only five, four, three, two, or one colour would be used instead of six. In the case of diminished form-perception, only five, four, three, two, or one form-unit would be used instead of six. In the above examples the results would only be approximately correct, because approximate psycho-physical units would be used; thus all greens would be represented by one colour. To obtain perfectly correct results, we should have to use absolute psycho-physical units.

What under ordinary circumstances is the result of diminished form-perception? It is that persons with this defect do not perceive differences of form which are evident to other persons. It is a very common occurrence for two persons to be looking over a photograph album and one to say, "These men are brothers, are they not?" and for the other to reply, "Yes; but how could you tell? There's not the slightest resemblance between them." But the original speaker declares that he sees a striking likeness. The reason of this is, that the man who fails to perceive the likeness has a psycho-physical form series the units of which are far less numerous than those of his friend, and so he is not able to perceive a difference less than that of the difference between two of the units. This may be made plainer with a simple illustration. Let six figures be drawn on paper, four being perfect circles, but the other two differing from circles in having one diameter slightly shorter than the other. Now, the above person would say that these were six exactly similar figures, the difference between the units of form making up the figures being less than that between the units of his psycho-physical form series. His friend would recognize the "likeness" between two of the circles. The countenance varies very considerably in different persons; but the above shows how a person with a deficient perception of form is often at a loss for a means of identification. Therefore, as the distance between the adjacent psycho-physical units increases so does the means of recognition diminish. A picture may be inaccurate in colour, form, size, or shade, and a person with ability for perceiving differences of form, but not those of size, will detect minute errors of form, but overlook very great errors in perspective and other points depending upon size. I have a friend who is par-

ticularly quick at noticing differences of size; and his remarks when observing pictures are nearly always connected with size—thus the length of the arm of one man is out of proportion to the body, the height of a church in the distance is too great, etc.

In the perception of shade we may have a physical series in which the units vary from white to black. A person with defective perception of shade will put two shades of gray together as exactly alike when the match is markedly incorrect to a normal-sighted person. This defect is not necessarily associated with diminished colour-perception. Thus we may meet with a person who has excellent shade-perception, but very defective colour-perception, and *vice versâ*.

Observers do not take sufficient account of mental deficiencies of perception when reasoning upon the functions of the senses. Thus we cannot say for certain that a photograph represents the image on the retina; in reality it may be far more complicated. It must be remembered that the impression of the photograph has to pass through the same channel (the eye, optic tract, and brain) before it reaches the mind; thus, if there were no colour-perceiving centre, we should have no knowledge of colour however plainly it was represented in the retina. An illustration will make this clear. If total colour-blindness were universal in man no correct idea could possibly be formed of the coloured image on a rabbit's retina, because that colour would be as much lost as any other. It seems to me very probable that animals possess perceptions which are not found in man, and we have no means of finding out what these are.

CHAPTER IV.

THE PSYCHO-PHYSICAL PERCEPTION OF COLOUR.

In this chapter I propose to show what we should theoretically expect on applying the theory of psycho-physical perception to the perception of colour, with the spectrum as the physical series. This chapter, like the last, is almost entirely theoretical, the predictions being made in accordance with the theory. It will be found that the facts obtained by experiment are identical with the predictions of the theory in the minutest particular, and therefore form the strongest presumptive evidence of its truth. If the reader find difficulty in comprehending the theory as described in the foregoing chapter, let him consider that the whole theory is one of perception of difference, and work out on paper the effects of a lessened perception of difference. According to this theory, persons who are colour-blind confuse colours, not because there is any colour loss or alteration in the physical basis of colour, but because they cannot see any *difference* between the colours.

1. The Physical Series of Colour.—It is evident that before we can have a psycho-physical series, we must have a physical series; and this is admirably represented in the case of colour by the solar spectrum. This is the most perfect example of a physical series which can be obtained. By dispersion the sun's light is spread out in the form of a series, the wave-lengths of the units gradually

diminishing from the red to the violet. The presenee of gaps in the solar speetrum in the shape of Fraünhofer's lines shows that the series is not a perfect one. The presenee of a very large number of Fraünhofer's lines shows that the speetrum is pure, and that the rays of light do not overlap.

The points of greatest difference may be obtained by measurement of the wave-lengths. It is evident that the two points of greatest difference do not eome within the visual range at all, because the waves in the infra-red present a greater physical eontrast to those in the ultra-violet than any two rays in the visible spectrum. If we take the portion of the physical series represented by the speetrum, the two points of greatest physieal difference are the first visible ray of red and the last visible ray of violet. The third point of greatest physical differenee will be some point near the eentre of the spectrum. The next two points will be found between the third point of difference and the ends of the spectrum. These and subsequent points ean be found with the aid of mathematical equations.

2. The Psycho-physical Series of Colour.—When a physieal series has been obtained, the mental impression of this series constitutes a psyeho-physical series. The appearanee of the speetrum to any person eonstitutes the psycho-physieal eolour series for that person. The question then is, What is the appearanee of the speetrum to the majority of persons? Most persons say that they ean see six definite colours in the spectrum—red, orange, yellow, green, blue, and violet; and that one eolour appears to shade off into those adjacent to it. We can examine the spectrum in another way—that is, by only observing a small portion at a time, either using shutters to a speetroseope, or letting the speetrum pass through a slit

which only allows a small portion to pass. When the spectrum is viewed in this way it appears to be made up of a series of monochromatic bands. The size of these monochromatic bands differs with different persons; that is, a band which is monochromatic to one person is not necessarily monochromatic to another. These bands are absolutely monochromatic; that is, if a portion of green were taken, the observer could not say which was the yellow and which was the blue side of the portion of light shown. But we know that the portion of light, though apparently monochromatic, contains rays of light which differ very considerably in wave-length, therefore we have a number of physical units which cannot be distinguished from each other. These units are seen under the most favourable circumstances for the detection of any difference, the adjacent colours being excluded, and yet they appear alike. The first obvious inference to be drawn from this is, that the rays of light occupying a monochromatic band are identical for the observer as far as perception is concerned. In the psycho-physical colour series, therefore, the absolute psycho-physical colour units are portions of the spectrum which appear—when the remainder of the spectrum is shut off—monochromatic. For example, take the several varieties of green which we can distinguish. As the band of colour appears monochromatic, we could substitute an equal number of any one of the rays of light entering into its formation, without altering its appearance as far as colour is concerned. From this it is evident that nearly all the experiments which have been made by physicists with regard to colour will have to be looked at from a psycho-physical standpoint, as this is a source of error which appears to have been very generally overlooked. As we can only tell an absolute psycho-physical colour unit from the adjacent units by carefully comparing them,

it is evident that the difference between them is not sufficient for practical purposes, so we come to the approximate psycho-physical colour units, that is to say, colours which can be easily distinguished from each other without comparison.

These approximate psycho-physical units, for a normal-sighted person, are six in number—red, orange, yellow, green, blue, and violet.

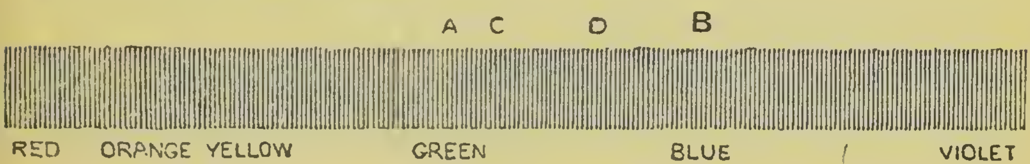

Fig. 11.

The above diagram represents a spectrum as seen by a normal-sighted person. A and B represent the centre points of approximate psycho-physical units, green and blue; that is, colours corresponding to these portions of the spectrum would be easily distinguished without comparison. The rays included between A and C form an absolute psycho-physical unit; that is, the portion of light included between A and C appears monochromatic. If shutters were used to the eye-piece of the spectroscope, the observer would not be able to say which was the yellow and which was the blue side of the portion of light shown. If, however, he were shown the coloured band from A to D he would be able to distinguish between the colour at A and that at D. But if he were shown a colour corresponding to D, and were asked to which portion of the spectrum it corresponded, without being allowed to compare it with other colours, he would find great difficulty in indicating the right position. There are, therefore, six definite points of difference in the spectrum, to a normal-sighted observer, corresponding to the centre of each of the colours, red, orange, yellow, green, blue, and violet.

As each of the colours at these points must by the presence of the adjacent points blend with each other, we have the approximate psycho-physical units formed. It will be seen that if the size of the absolute psycho-physical units, as A C, be increased, the size of the approximate units will also be increased. As the spectrum remains the same length, the increase in size of the approximate units results in their re-arrangement and diminution in number, and hence colour-blindness. In the first degree of colour-blindness, five instead of six distinct points are seen in the spectrum. In the next degree four, and so on, until total colour-blindness is reached.

To return to the theoretical aspect of colour. We have to consider what are the points of difference in a psycho-physical series of which the spectrum is the physical series. Let us suppose that we have a spectrum, and have to consider in what order the points of difference appear according to the number which a person is able to see. It is evident that if the perception of difference were very defective, the spectrum would appear colourless and simply brighter or darker, according to the intensity of the light; a person of this kind would be totally colour-blind, and the whole of his spectrum could be matched with varying proportions of white and black—that is, gray. If the perception of difference were not quite so defective as this, the extreme ends of the spectrum would appear feebly coloured, and the remainder gray. The spectrum would appear as nearly all gray, but with a tinge of red at one end, and a tinge of violet at the other. It will be seen that as perception improves, the tinge of red and tinge of violet will invade the gray and approach each other, because the wave-lengths need not be so proportionately different before a difference is seen. It is obvious that all the colours of the normal-sighted which are included in

the coloured portions of the spectrum will be seen alike, and may be represented by that colour of the normal-sighted which corresponds to the centre of this coloured portion. It is obvious that no difference will be seen in colour between the various portions of the coloured band, because if a person is not able to see any difference between yellow and blue, it is evident that he will not see any difference between red and orange. What are the two colours seen when the whole of the gray has disappeared? As I have shown, the colour will be represented by that colour which in the normal-sighted corresponds to the centre of each of the two colours. According to the theory, these centre points ought to correspond to the centres of the two halves of the physical colour series. The two colours should be complementary to each other. It is evident that these complementaries must be those which are closest to each other as far as the spectrum is concerned. The complementaries which are adjacent to each other are yellow and blue.

These colours are the yellow and blue, having the wave-lengths 2120 and 1781 respectively, the ratio of the wave-lengths being 1·190. These two colours should meet in the green.

The next step will be the formation of another point of difference at the centre of the series; that is to say, there will be three definite points of difference instead of two. These three points of difference will be the centres of the terminal psycho-physical units, and the centre of the spectrum; that is to say, the three points will be the centres of the red, green, and violet, of the spectrum.

It will be noticed in a psycho-physical colour series, in which a person is able to see three colours, that the two points of greatest difference will be between the points of difference of a person who is only able to see

two colours and the ends of the spectrum, because his approximate units are smaller. Taking, for convenience, the centre point of an approximate unit as representing that unit, it will be noticed, that as more colours are seen, these points are gradually moved towards the ends of the spectrum. In the normal-sighted, therefore, the two colours presenting the greatest contrast are the red and violet.

There are many persons who, whilst admitting readily enough that the three points of greatest difference in the spectrum are the red, green, and violet, would object to red and violet being the two points of greatest difference. It is evident enough, in the series of discs, that the largest disc presents the greatest contrast to the smallest one; and, in the sound series, it is evident that the deepest bass notes form the greatest contrast to the highest treble, provided that both are heard distinctly. There are several reasons why violet should not, at first sight, appear the colour most strongly contrasting with red. The most important reason is, that very few of the violets met with in nature are pure—that is, the object is found to reflect some of the red rays in addition. If we compare monochromatic strips of spectral colour we shall see that true violet presents the greatest possible contrast to red. The difference is admirably illustrated by using the terms warm and cold, which artists have applied to these colours. Again, when violet is contrasted with blue the former does acquire a reddish tinge, which is due to the effects of simultaneous contrast. It is of the greatest importance that when one colour is being considered, the others should be excluded.

The other reason for not regarding red and violet as the most dissimilar colours, is that violet is regarded by most persons as a mixture of red and blue. But red and blue do not make violet, as will be seen by mixing the

pure spectral colours. Red and blue make a purple, which plainly shows the element of red. Violet is a colder colour than blue, and, instead of being a transition colour between blue and red, it is more unlike red than blue. Let the reader look at spectral violet, and he will be unable to detect any red element whatever. This shows that colours must be looked at as forming a series, not a circle. As red and violet, and red and blue can be combined we have a double series, one consisting of the spectral colours, and the other consisting of hues of purple. Those who look at colour from a physical standpoint, regard the complementary of any colour as that which contrasts most strongly with it. It will be found, on referring to the chapter on the physiological phenomena of colour, that this is not the case.

Another point for consideration is: Shall we take the end members of the series as the points of comparison? In looking at the series of discs to which I have referred, we should naturally take Nos. 1 and 20 as forming the greatest contrast. But this would only be on account of the knowledge we possess that No. 20 is the largest disc, and No. 1 the smallest. For all practical purposes, No. 19 presents quite as great a contrast to No. 1 as No. 20 does. If we cannot distinguish any difference between members of a series, as far as we are concerned, they may be considered to be exactly alike.

It is evident that there is an absolute psycho-physical unit at each end of the colour series, represented by the spectrum. I have defined an absolute psycho-physical unit as a portion of a physical series, in which it is impossible to see any difference between the members of the series, even under the most favourable circumstances, and with the most careful comparison. Then, not only the end member of the series, but any one of the members, included in the

absolute psycho-physical unit, might be taken to represent the unit, without in any way affecting the result. In addition to there being an absolute psycho-physical colour unit at each end of the spectrum, there is an approximate colour unit, and these are the colours red and violet. As an approximate colour unit consists of a portion of a physical series, the members included being not easily distinguished from each other, and so much alike as to be called by the same name, *cæteris paribus*, the central point of this unit will be that which is most representative of the colour. If any portion of the unit presented any marked difference in intensity, it is probable that the most intense portion would be selected.

Having shown how the psycho-physical colour series appears with three approximate psycho-physical colour units, we must consider where the fourth point of difference would be situated. As I have stated in the last chapter, if the units of a physical series differ from those adjacent to them in a proportional manner, the fourth and fifth points of difference will appear at the same time, and be situated at points midway between the centre and ends of the series. The units of the light series do not differ in a proportional manner if we are to regard the wave theory of light as the correct one. Therefore, in the psycho-physical colour series the fourth point of difference will appear before the fifth, and be situated at the point of greatest difference. The waves of light at the red end of the spectrum are larger than those at the violet end, and, therefore, the fourth point of difference will appear at a point midway between the red and the centre of the green, namely, the yellow. An example with smaller numbers will show why the fourth point of difference should appear on the red side of the green. Let us suppose that we have a series of vibrating members, the vibrations being

from 5 per second for the lowest member, to 105 per second for the highest member. There will be much more difference between the first and second member of the series than between the last member, and the one just before it. In the first case there will be a difference of $\frac{1}{5}$, in the second case $\frac{1}{104}$, a very much smaller fraction. The fifth point of difference will appear midway between the violet and the centre of the green. The sixth point of difference will appear on the red side of the fourth point of difference. There will then be two points of difference between the red and the centre of the green, namely, orange and yellow. It is evident that when orange is seen, the fourth point of difference—namely, yellow—will appear to have moved more towards the green, the fourth point of difference now being a combination of the two, namely, orange-yellow. This can be seen to take place if a spectroscope be arranged so that no orange is seen. A spectrum of this kind can be obtained with a fine slit; on slightly widening the slit so that more light is admitted the orange will be seen, and the yellow will appear to change its position and move towards the green. The seventh point of difference will appear between the green and the violet; that is to say, there will be two points of difference, or colours seen, between the green and the violet, instead of one. It is not necessary to consider the extension of the series any further, because I have not met with a person who could see more than seven colours in the spectrum. The series could be extended *ad infinitum*, the extra point of difference being put first on the red side of the green, then on the violet side.

I have now discussed the theory of psycho-physical perception in its application to colour. I have shown what we should expect from this theory in its relation to colour-blindness. The question is: Are these predictions

fulfilled? Yes; they are, in the minutest particular. Not only does this theory explain all the phenomena of colour-blindness in the most complete manner, but it accounts for a number of phenomena which were previously unexplainable.

On referring to the frontispiece, it will be seen that the majority of persons see six colours in the spectrum, and that these colours appear at the points which I have predicted.

In some cases seven colours are seen, and then the seventh colour appears at the point where it should appear by theory. In the first degree of colour-blindness only five colours, or points of difference, are seen in the spectrum; in the next degree four; in the next, three; then two. Then a neutral band appears in the centre of the green, and this increases in size in different cases until total colour-blindness is reached. Therefore, the vision of the normal-sighted being hexachromic, the vision of the colour-blind is pentachromic, tetrachromic, trichromic, or dichromic. It will be noticed that the greatest difference is to be found between the three-unit and the two-unit cases of colour-blindness, the primary colours for each being quite different. The two primary colours for the two-unit are yellow and blue, and they each represent half of the spectrum. In the case of the three-unit the three primary colours are red, green, and violet. Red combined with green forms yellow; violet combined with green forms blue, so it is evident that these colours occupy the positions which I theoretically allotted to them.

The following will give the normal-sighted reader the best idea of this theory of colour-perception and the various phenomena of colour-blindness. He knows that he can see six definite colours. Let him for the five-unit imagine that five of his adjacent colours are spread over the spectrum;

for the four-unit, four; for the three-unit, three; for the two-unit, two; and for the one-unit, one. Looking at the subject in this way, he will at once comprehend how it is that the colour-blind are able to recognize colours and correctly name them. As an example of this method of looking at the subject, let us represent the two-unit by the two adjacent units, blue and green. It is obvious that a normal-sighted person could distinguish different colours, even if only two were visible to him. Then colours might be named in the following way. A dark but pure green would represent red; a very bright green, orange; the brightest possible green, yellow; a bright but not quite so pure green, yellow-green; a duller and not so pure green, pure green; a mixture of the two colours, blue-green; a blue, with a trace of green, blue; the purest possible blue, violet. It will be noticed in the following chapters that this is how a certain two-unit learned to distinguish between colours, and his friends have great difficulty in getting him to name them wrongly. Again, if we consider the three-unit as represented by the three colours, red, orange, and yellow, of the normal-sighted, we see how a mixture of red and violet gives rise in the three-unit to a sensation very similar to green, as a mixture of red and yellow with the normal-sighted gives rise to a sensation very similar to orange.

To the colour-blind, colour as a quality of objects is much less than it is to the normal-sighted, and in direct proportion to the degree of colour-blindness. For this reason the colour-blind rarely make remarks about colour, and generally say that it interests them very little. In the three-unit the three most distinct colours are red, green, and violet—that is to say, the centres of their three psycho-physical units. In the simple two-unit the colours which are best seen are yellow and blue, the centre colours

of each of the units. This is a point which all simple two-unit colour-blind agree about; they say that the yellow buttercup and the blue sky give them the strongest and most contrasted sensations of colour. The three-unit find that they have a large number of superfluous colours; their vision is trichromic, whilst that of the two-unit is dichromic. The apparently superfluous colours will be confused with those which they can see distinctly; this will be especially the case with purples, browns, and grays. Rose, made up of a mixture of red and violet, is a colour with which they find especial difficulty, and according to the proportions of red and violet will the colour be classified; thus a purple containing less red than violet will be classed with the violets, whilst a rose-red containing more red than violet will be classed according to its shade with red, orange, or yellow. A rose which consists as nearly as possible of equal parts of red and violet will often be mistaken for green, in the same way as the normal-sighted fail to distinguish an orange made up of red and yellow from a pure orange reflecting the orange rays of the spectrum. The close relation which purple, green, and gray have to each other, even for the normal-sighted, is shown by the changeable silks of my Pocket Test.

Colour to a person seeing the spectrum like Fig. 9 is scarcely a quality of objects at all. The individual from whom this diagram was constructed was a case of four-unit colour-blindness for the left eye, and this condition for the right: he said that to the right eye the spectrum looked as if it were nearly all gray, but with a tinge of red at one end and a tinge of blue at the other. The case is described in full further on in this book.

With regard to the colours seen by each, the most typical colour will be that corresponding to the central point of

each unit. For the sake of uniformity I have not represented this in the diagram. Thus the first unit in Fig. 6 should be represented by yellow, the second by blue-violet, because these colours correspond to the central points of each unit.

The number of approximate psycho-physical units seen by any individual in the spectrum will be the number of colours he is able to see, and under no circumstances will he be able to see more than this number. We also know that if any two colours belonging to adjacent units be mixed—for instance, blue and green—we obtain a mixture which is not a fresh colour, but one possessing the characteristics of both of its components,—that is, a modified unit. Also in many cases, if we mix the colours belonging to two units, not being adjacent ones, we shall obtain a colour corresponding to that lying between the two. From these facts we can deduce definite laws of colour-perception which are applicable to all cases.

1. An individual can have no conception of a colour which does not form one of his psycho-physical colour units, or a very apparent modification of one of those units.

2. If the colours belonging to two adjacent units be mixed, an impression of both units is obtained which is plainly perceived as a mixture.

3. If two colours, not being adjacent units, be mixed, the colour between the two will tend to be revived and brought before the mind, or white will be the result in the case of pure light, gray when there is partial absorption.

4. If any number of colours be mixed, the resulting impression will be that of a unit, a modified unit, or white.

There are other alterations in a sensation which have to be taken into consideration in individual cases, besides those described in detail above. I have mentioned the influence of the sense-organ in limiting a psycho-physical

series, but the sense-organ might directly alter the apparent colour of a body through absorption; that is, the colour will be relatively different from that of other persons. For instance, the crystalline lens has a tendency to become yellow with age: all objects to a person of this kind will appear yellower than they would to a person with a normal lens. These details will be discussed fully in the chapter on the Qualitative and Quantitative Estimation of Defects of Colour-perception.

The Effect of a Shortened Spectrum upon Psycho-physical colour-perception.—In the preceding pages I have considered the effect of a lessened perception of difference, the length of the psycho-physical series being the same in each case.

The effect which shortening of the psycho-physical colour series from any cause would have upon psycho-physical colour-perception now remains for consideration.

The first obvious effect would be, that the portion of the series which was not perceived would, for that individual, be practically non-existent. Therefore, any colour consisting only of these rays would appear black, and these rays would have to be subtracted from the composition of any colour in which they formed a component part.

The junctions of the various colours will also be slightly different from that of the corresponding class with a spectrum of normal length. It is obvious that the perceptive centre can only be cognizant of sensations which are conveyed to it, and sensations which are not conveyed to it are for all purposes of perception non-existent. For instance, let us consider the positions of the junctions of the units in a case of three-unit psycho-physical perception with shortening of the red end of the spectrum. This limited spectrum will have to be divided into three, and then it will be found that both the red-

green and the green-violet junctions are situated at points occupying positions nearer the violet end of the spectrum than the corresponding junctions of those with a spectrum of normal length. The red-green junction, therefore, in a case of this kind, will be situated in the yellow-green instead of in the yellow as it is in three-unit cases with an unshortened spectrum.

On referring to the details of the cases which I have given, it will be found that these theoretical predictions are verified in every particular.

CHAPTER V.

THE FUNCTION OF THE RETINA IN THE PERCEPTION OF COLOUR.

The Structure of the Retina.—The retina may be conveniently divided into ten layers.

1. *The Pigmentary Layer.* Many writers describe this layer as part of the choroid, but the study of its development shows that it forms part of the retina. It consists of a single layer of hexagonal nucleated cells. These cells are pigmented, and have processes which extend into the layers formed by the rods and cones.

2. *The Rods and Cones.* Each of these bodies consists of an outer and an inner segment. Their long axis is perpendicular to the surface of the retina. The rods are cylindrical and nearly of uniform size. The cones are flask-shaped, the smaller end of the flask pointing to the external surface of the retina. At the yellow spot there are no rods.

3. *The External Limiting Membrane.* This is formed by the expansion of the external extremities of the fibres of Müller. These fibres of Müller form the connective-tissue framework which supports the various layers of the retina.

4. *The Outer Granular Layer.* This layer is made up of nucleated oval cells which are connected with the rods and cones on the one hand and the cells of the inner granular layer on the other. The cone granules—that is,

those cells which are in connection with the cones—are situated nearer the external limiting membrane than the rod granules.

5. *The Outer Molecular Layer.* This consists of molecules and fine fibrillæ.

6. *The Inner Granular Layer.* This layer chiefly consists of nerve-cells which are bipolar and nucleated. The outer processes anastomose with fibres from the rod and cone granules. The other process is lost in the inner molecular layer.

7. *The Inner Molecular Layer.* This consists of molecules and fine fibrillæ, being similar in character to the outer molecular layer.

8. *The Layer of Ganglion Cells.* These are multipolar cells. They are connected with the axis cylinders of the optic nerve-fibres, and externally with the inner molecular layer.

9. *The Nerve-fibre Layer.* This consists of the expansion of the fibres of the optic nerve.

10. *The Internal Limiting Membrane.* This separates the nerve fibres from the vitreous humour. It is intimately connected with the fibres of Müller.

The Physiology of the Retina.—The rods and cones of the retina are practically the terminations of the optic nerve, and directly sensitive to the influence of light. It is not known what are the relative functions of the rods and cones. It is stated that the rods cannot be necessary for colour vision, because they are absent at the yellow spot, the region in which form and colour vision are most distinct.

The ordinarily accepted theory with regard to the conversion of light undulations into a sensation, is that light passes through the retina, and is reflected back from the choroid. The undulations on their return through

the retina influence the rods and cones. The effect of this influence is a molecular movement which is transmitted to the brain, and becomes evident as a sensation of light.

It is difficult to understand how it is that the light waves do not influence the rods and cones in their first passage through the retina.

In the outer limbs of the rods a purple substance is found which is sensitive to light. This purple is sensitive to monochromatic as well as to white light. It is bleached most rapidly by the greenish yellow rays, those to the blue side of these coming next, the least active being the red. This visual purple is found exclusively in the rods. Under the action of light the visual purple first becomes yellow and then colourless.

The chief arguments which have been used against the view that the visual purple is an essential element in vision are—its conspicuous absence from the cones, and frogs whose retinas have been bleached by exposure to light appear to be as sensitive to colour as other frogs.

I am inclined to think that this visual purple is one of the essential elements in vision, and that the process might take place in the following manner. That light acting upon the visual purple causes its liberation from the rods. This, becoming diffused at the back of the retina, forms an actual photograph of the objects included in the visual field. The function of the cones might be that of conveying this impression to the brain. The absence of rods from the yellow spot might be explained by the assumption that the visual purple which is liberated from the rods surrounding the yellow spot is diffused into this spot in sufficient quantity for distinct vision, and that if there were rods in the yellow spot the quantity liberated would be too great, and would interfere with distinct vision.

This view is supported by the following experiments,

which I instituted on purpose. If we look at a gas flame through a pin hole in a sheet of paper, the flame appears to have lost the greater portion of its luminosity. If we remove the paper with the pin-hole further from the eye, and so that light from adjacent objects can enter the retina, then the gas flame again resumes its original luminosity. For the purpose of experimenting in this way, I obtained a piece of black velvet, and, having cut a square hole in the centre, I pasted a piece of cardboard on the velvet over the hole. The internal surface of this cardboard I blackened with ink. I then pricked a pinhole in the card from within outwards. When this hole is close to the eye, we can see not only the gas flame, but the whole of the gas-globe. The eye is constituted so that any given portion of the retina can only receive light from one object in the visual field. Therefore, whether we are looking at the gas flame directly, or through a pinhole, the portion of retina upon which the image of the gas flame falls receives a proportional amount of light. When we are looking directly at the gas flame, the image of this flame falls directly on the yellow spot. Now let other objects be viewed through this pinhole, and it will be found that unless an object be brightly illuminated, it will not be visible at all. On looking at the fire the yellow flames can be seen of greatly diminished luminosity, but the red glow of the fire is not visible at all. A diminution in luminosity is produced by cutting off some of the rays from the retina, namely those which under ordinary circumstances would fall on the peripheral portions of the cornea, but I do not think that this could account for the very great diminution in luminosity which occurs, and the fact that dimly illuminated surfaces and the red glow of the fire are not visible at all.

If this theory be true, the importance of the iris is greatly increased. By its action the amount of light which enters the eye is regulated. The dilatation of the pupil in darkness would be necessary in order that a photographic image might be obtained, and its contraction when the eye is exposed to a strong light necessary in order to prevent more than the requisite amount of light from entering the eye.

The following are a summary of the results obtained by Kühne * with regard to the visual purple.

1. That it is found in the outer segments of the rods only.

2. That it gives a continuous spectrum.

3. That by its means we can obtain definite photographs on the retina of an excised eye, and that these photographs may be fixed.

4. That it is bleached most rapidly by the greenish yellow rays of the spectrum, then by the green, and least of all by the red.

5. That it becomes yellow, then white, under the action of light.

6. That it is soluble in a solution of the bile salts. The purple fluid thus obtained reacts to light in the same way as normal visual purple.

7. That after being bleached it was regenerated by the pigmentary layer of the retina.

8. That it is bleached by monochromatic as well as white light.

The following experiment, which was first noted by Helmholtz, lends considerable support to the theory which

* Zur Photochemie der Netzhaut. "Ueber den Sehpurpur," Verhandl. d. Naturhistorischmed. Vereins in Heidelberg, Bd. I., 1877. Sehen ohne Purpur, "Untersuch. physiol. Instit., Heidelberg," Bd. I., 1877. Ewald and Kühne, "Ueber den Sehpurpur," *ibid.*

I have advanced with regard to the visual purple. He says—*

"I would invite attention to the fact, that when very bright light of any kind whatever falls upon a portion of the retina, light of the same kind appears diffused as a weak luminosity over a great portion of the field of view. The phenomenon is easy to be observed. Let a candle be placed in the evening in the neighbourhood of a large dark surface—for instance, of a door which opens into a dark room,—and let the degree of darkness of the surface be observed while the light is alternately concealed by the finger and allowed to strike the eye. It will be readily seen that as often as the rays freely enter the eye, a white luminosity appears spread over the surface, being brighter in the vicinity of the light, and spreading itself weakly over the more distant portions of the surface. The same is observed when daylight enters the eye from an orifice in a dark screen. When the orifice is covered by a coloured glass, the luminosity has the colour of the latter."

Helmholtz is of opinion that the phenomenon is due to reflection of light from the posterior surface of the iris, but it seems to me that, if this explanation were a true one, the light would be reflected in an irregular manner, and not diffused over a large surface. If we accept the view that the visual purple is liberated from the rods by light, and diffused over the retina, the phenomenon is intelligible, as is the fact that the luminosity is brighter in the vicinity of the light.

Might not night-blindness be caused by destruction of a considerable number of the rods, and the visual purple which is contained in them? If the quantity of visual purple were defective, a stronger light would be

* *Philos. Mag.*, Dec. 1852, p. 406.

required for its diffusion into the region of the yellow spot.

I am inclined to regard the arguments which have been advanced against the view that the visual purple has an essential part in vision, as easily explainable on the above theory. According to the theory which I have advanced, it would be absolutely necessary that there should be no visual purple in the cones, these being regarded as the conducting bodies. There are many difficulties in the way in experimenting with a substance of this kind: thus the purple colour may be the first change in the bleaching process. The argument that frogs whose retinas have been bleached see as well as frogs with unbleached retinas, is fallacious, because the pigment-cells of the retina may be secreting sufficient of the visual substance for vision, but not sufficient for external recognition. The presence of this substance is what I should have theoretically expected on the psycho-physical theory. Its presence enables us to transfer the resolution of the visual image from the retina to the brain. It is easy to understand how the photograph on the retina is conveyed to the brain through the cones and optic nerve fibres.

It will be noticed that the visual purple gives a continuous spectrum. It is probable that in persons with a shortened spectrum the visual purple would be found to give a spectrum shortened in the same way.

The following observations by Mr. Gunn are of great importance. He says: * "The changes produced in the vertebrate retina by the action of light may be classified as (1) Photo-Mechanical, (2) Photo-Chemical, (3) Photo-Electrical."

* "On the Nature of Light-percipient Organs, and of Light and Colour Perception," by R. Marcus Gunn, F.R.C.S., *Royal London Ophthalmic Hospital Reports*, vol. xii., part 2.

1, *a*. The best-known photo-mechanical change consists in a wandering of pigment inwards within the fine protoplasmic processes of the pigment-cells. A short exposure to a bright light suffices to bring about a distinct wandering of the pigment, and the more refrangible rays seem to act most powerfully, the red rays least, and the yellow rays with an intermediate strength.

b. Recent observations of Van Genderen Stort and Engelmann have made us acquainted with a second example of photo-mechanical action in the vertebrate retina, viz., a shortening of the inner segments of the cones under the action of light, and an elongation in darkness. On exposure to light, therefore, the outer segments are drawn towards the outer limiting membrane, and *away from* the pigment-cells, while in darkness the opposite movement takes place.

2, *a*. Photo-chemical action is illustrated by the bleaching of the retinal purple in the rod outer segments on exposure to light, and by its re-secretion in the pigment-cells, especially in darkness.

b. Another photo-chemical effect on the retina, that is as yet very imperfectly known, will, I think, ultimately prove to be of much importance, viz., the alteration in the reaction of the contents of the pigment-cells due to light-exposure. This seems to be an oxidizing process accompanied by the substitution of an acid for a previously alkaline reaction.

3. It has been conclusively demonstrated that the action of light upon the retina is accompanied by an increase of the normal electrical current passing along the optic nerve to the brain. Different parts of the spectrum produce different amounts of increase, the yellow rays having the greatest power. From this part of the spectrum we have a gradually diminishing action on

either side until we reach the ultra-red rays on the one hand, or the ultra-violet on the other, when it is found that no change whatever is produced in the electrical current by these non-luminous waves.

CHAPTER VI.

NORMAL COLOUR-PERCEPTION.

THROUGHOUT this book I use the term "normal" to signify the colour-perception of the large majority of persons, namely the six-unit. Fig. 2 of the frontispiece represents the spectrum as seen by this class of persons. The proportion which the six-unit bears to the other classes is about twenty in twenty-five. About one fifth of the number of educated persons of the male sex whom I have examined have had a diminished colour-perception. The class of the seven-unit is rare, not more than one person in several thousand seeing seven colours in the spectrum.

Since the time that Newton described the principal colours of the spectrum as being red, orange, yellow, green, blue, indigo, and violet, most writers have adhered to the division. Latterly, however, some writers on colour have demurred at the insertion of indigo, and especially at its insertion between blue and violet. If a six-unit were asked to make seven colours he would add greenish yellow to the list. It has also been pointed out that indigo is a green-blue and not a violet-blue, and therefore could not be placed between the blue and the violet. But under some conditions indigo appears as a violet-blue.

The six-unit is the class to which I belong, therefore a description of my own colour-perception will serve as an example. I see six definite colours in the spectrum—

red, orange, yellow, green, blue, and violet. These colours have the proportions marked out in Fig. 2. If a spectrum be looked at as a whole, it appears as if one colour gradually passed into another, in such a way as to make it difficult to mark out the exact junction of the units. However, when shutters are used to the eye-piece of the spectroscope, all but a small portion of the colour may be excluded. The junction can then be found with ease. I see no trace of the indigo of Newton in the spectrum, the blue gradually passes into the violet without any change in the nature of the blue. The junction of the blue and green of the spectrum has a peculiar appearance to me. The colour is not what is usually understood as a blue-green, but appears as if the two colours overlapped at this point, just as if the torn edge of a piece of blue tissue-paper were made to overlap a similar edge of green tissue-paper. The edge looks attenuated, just as paper does when torn in the wet condition. I have not found any one who possessed a spectrum of greater length than myself; the majority of persons see the spectrum of the same length.

In this chapter I wish to show how colours should appear, and the standards of colour for comparison with other classes of persons.

A normal-sighted person sees six definite colours, and a little consideration will convince a normal-sighted person that this is the case. These colours are red, orange, yellow, green, blue, and violet. If we take a pure yellow and a pure blue and place them side by side, we see at once that there is no factor common to both. This fact is obvious, and it seems difficult to conceive by any stretch of the imagination that blue and yellow can possess a common factor. When, however, we come to deal with other colours, we find more difficulty in appreciating how

distinct they are from each other. This is due to artistic training and imperfect colours. For instance, with red and orange. The popular idea of red is erroneous, because pure reds are uncommon. In the pigments in common use there is not a pure red. Vermilion is an orange-red; Crimson Lake a violet-red. If we mix the two we get a fairly pure red, and this colour bears no resemblance to that of an orange. Again, many substances which appear yellow in thin layers or in weak solutions, appear orange if a thicker layer be taken or a stronger solution used. This has a great tendency to make casual observers think that orange is really only a deep yellow. A few experiments will, however, demonstrate the cause of this. Let us take, for example, a solution of Methyl-Orange. In a dilute solution the colour appears as a very pure yellow. The transmitted light, being examined by the spectrum, is found to consist of the red, orange, yellow, green, and most of the blue-green and violet rays. No blue rays are visible. A slightly stronger solution being used the colour appears as orange-yellow, and the transmitted light, being examined with the spectroscope, is found to consist of red, orange, yellow, and the yellow half of the green rays. The remaining rays of the spectrum are completely absorbed. If a still stronger solution is made, the colour appears as a pure orange. The transmitted light being examined with the spectroscope is found to consist of the red, orange, and yellow rays. If a stronger solution is used the colour appears as orange-red; if a very strong solution is used the colour appears red, only the red rays being transmitted. The red rays of the spectrum are by far the most penetrating, and, if a substance be transparent to these rays at all, the probability is that a thick layer of the substance will appear red. It is obvious that a classification of colours may be made with the spectrum for a basis; and, as a

matter of fact, the spectral colours are the purest. We therefore start with red, orange, yellow, green, blue, and violet. If we take two varieties of modified units it will be sufficient for all practical purposes, naming the preponderating colours last. The series will therefore be red, orange-red, red-orange, orange, yellow-orange, orange-yellow, yellow, green-yellow, yellow-green, green, blue-green, green-blue, blue, violet-blue, blue-violet, purple, rose and rose-red. If we wish to make smaller divisions we can do so after the manner of the compass; thus green-blue-blue would indicate a colour midway between green-blue and blue. The modified unit lying between red and violet occupies a peculiar position, and it is necessary to have more than two divisions. The first colour is rose, made by mixing equal parts of red and violet, and complementary to pure green. Then we can have two more colours—purple, consisting of equal parts of rose and violet; and rose-red, made of equal parts of rose and red. The above classification is the one which I have adopted throughout this book.

In looking at the subject of colour from the standpoint of the normal-sighted, we must keep very closely to the theory of psycho-physical perception. We know that under ordinary circumstances six definite colours are seen. Let us consider how the spectrum looks to the normal-sighted under conditions of varied intensity. On looking at the ordinary solar spectrum we see that there are six colours having the proportions marked out in Fig. 2. If we diminish the intensity of the spectrum by using a finer slit for admitting light, we shall see that the spectrum changes in the following manner. First the orange band disappears, and the spectrum has a very similar appearance to that marked out by the five-unit. On still further diminishing the slit the blue disappears, and we have a very similar

spectrum to that of the four-unit. On still further diminishing the slit the yellow disappears, and we have a spectrum possessing the characteristics of that of the three-unit. On still further diminishing the size of the slit the violet disappears, and only a dull red and green are seen. On still further diminishing the slit a dull green is all that is seen. These observations show how the colour-perception of the normal-sighted may vary under different conditions. It will be noticed that a gradual diminution of intensity so far interferes with perception that it may reduce a normal-sighted person to a five, four, or three-unit. We cannot, however, reduce a normal-sighted person to the condition of the two-unit; that is to say, to the normal-sighted, red and green are always visible as definite colours, and under no circumstances are likely to be mistaken for each other. It will be noticed that, at a distance, modified units become indistinguishable from the ordinary units. As an example of this let us take three coloured glasses, blue-green, pure-green, and yellow-green, putting them in lanterns at some little distance apart. If we now walk backwards from these three lights we shall notice that the yellow-green and blue-green begin to get more and more allied, and at a certain distance the three become almost indistinguishable from shades of a pure green. It is always thus in looking at colours. The modified unit becomes indistinguishable from the unit which predominates in its composition. The modified units are rarely visible in fireworks seen at a distance. The colours of the stars might for all practical purposes be made of the six true units of colour. Some may think that an exception should be made in favour of the modified unit rose; but they will find it impossible to tell between a light red and a rose when viewed at a distance.

Colours may differ from each other in three respects.

1. Difference of Hue.—The best example of colours differing in hue is afforded by the spectrum. All colours must be either units or modified units.

2. Difference of Luminosity.—No coloured object can have the luminosity of a white object reflecting practically the whole of the light impinging upon it. Therefore, if we take absolute reflection as 100, a fraction of 100 will give the relative luminosity of any body.

3 Purity.—The third respect in which colours may differ from each other is purity, or freedom of the colour from admixture with white light. When I speak of a colour being mixed with white light, I have a different meaning from that which is signified by most writers on colour. By the fourth Law of Colour-Perception, if any number of colours be mixed the resulting impression will be that of a unit, a modified unit, or white. Some mixtures therefore appear white, others appear coloured. It is obvious that if we mixed these two mixtures we should get a colour diluted with white. A mixture of yellow and blue gives rise to a sensation of white, as does a mixture of blue-green and red; and yet these mixtures are quite distinct, so much so that there is not an element common to both. The action of the two whites on a photographic plate at once shows how dissimilar they really are.

Ordinary white light is made up of waves differing very considerably in their refrangibility, and has a constitution quite different from that which is made up of a mixture of yellow and blue light.

It will be seen, therefore, that a colour may appear to be mixed with white light and yet contain no true white light. An example will illustrate this. If we take a beam of sunlight and allow it to pass through a coloured substance which is perfectly opaque to the blue rays, but

transparent to the rest of the spectrum, we shall obtain a very bright yellow, apparently diluted with white light. We know that a large number of the rays have combined to form yellow; for instance, the yellow-green and orange, the pure green and red. The violet and blue-green would combine to form a blue. This blue would again combine with some of the yellow to form white, which would dilute the yellow previously formed.

It will now be as well to discuss the terms which are used by artists and many writers on colour. It must be borne in mind that we obtain nearly all our colours by absorption of one or more of the constituents of white light. The process, therefore, is one of subtraction, and not of addition.

We can obtain a series of colours of the same hue varying from the brightest and purest colour on the one hand, and to black on the other. The former series are called tints of the colour, the latter shades.

The terms used by artists are based on the assumption that red, blue, and yellow are primary colours. The so-called secondary colours are orange, green, and purple. The so-called tertiaries are obtained by mixing two of the secondary colours. They are really only simple colours mixed with gray or black. It will be found that the whole system of possible colours may be obtained with the three variables which I have given.

The majority of people see six distinct colours in the spectrum—red, orange, yellow, green, blue, and violet. They have, therefore, six units of colour. Each of these units forms the basis of a series extending from the lightest to the darkest possible colour. Many persons are under the impression that brown is a distinct colour. It is not, but a darker shade in either the yellow or orange series.

We can have a very numerous series of colours if the modified units are counted as distinct colours. We can have red gradually passing into orange; orange gradually passing into yellow; and so on, to the end of the spectrum: but it is obvious that we are not dealing with distinct colours, as we can distinguish the components of the modified unit. Thus with blue-green we can plainly see that the colour consists of green and an admixture of blue. This cannot be done with the true units of colour; thus, take the two colours which are commonly supposed to make green, yellow, and blue, and compare them with green. As representative pigments, Light Chrome, Emerald, Green, and Ultramarine may be used. The three appear entirely different colours, possessing no common factor.

The spectrum gives us the purest representation of each of the six colours, but in order that the reader may be able to form a fair idea of these colours without referring to the spectrum, I will mention a few objects representing as nearly as possible a pure unit of colour.

1. **Red.**—There is no pure red pigment in common use, all incline either to violet or orange. The common idea of red is an orange-red like Vermilion. A very fair red may be obtained by mixing Crimson Lake with Vermilion. Deep ruby glass is a very pure red. Claret is of a deep but pure red colour. The red-browns represent the deeper shades of red.

2. **Orange.**—Orange-peel is a very fair representative of a medium shade of this colour. Red lead is orange with a slight admixture of red. Saffron is also a very fair orange. It must be borne in mind that the deeper shades of orange do not incline to red, but form orange-brown. Copper represents a deep orange. The glow of a coal-fire is a very fair orange.

3. **Yellow.**—The pigment Pale Chrome is an excellent

example of yellow. Sulphur is also a good yellow. Deep yellow does not incline to red, but to yellow-brown. Tan is a good example of deep yellow.

4. Green.—The pigment Emerald Green is nearly a pure green. It inclines slightly to a yellow-green. Grass is a yellow-green.

5. Blue.—Ultramarine made from lapis-lazuli is the best example we have of a pure blue. A peacock's neck towards sunset is a very pure blue. This blue as daylight wanes becomes tinged with violet. A peacock's neck in full daylight is greenish blue.

6. Violet.—One of the best examples of a pure violet is the colour of the flower of some varieties of Lobelia, which is used so much in carpet bedding. The cornflower is also an example of a pure violet. Contrast a cornflower with a poppy, and the vivid contrast which red and violet form is apparent. The red colour of the poppy is heightened, and the violet colour of the cornflower also becomes of a more typical violet. The fact that red and violet form the greatest contrast of any two colours, becomes apparent in a marked degree. The best time to see a pure violet is towards sunset. At this time the violet rays are plainly visible, whilst the red rays are only imperfectly perceived. A very fair idea of a pure violet may be obtained by looking at a piece of light-blue glass, contrasted with a piece of intensely bright red glass. Simultaneous contrast prevents the red from being visible in the blue, and throws the latter into the violet. It also gives the violet the cold, chilly appearance of true violet.

CHAPTER VII.

THE COMPOSITION AND COMBINATION OF COLOURS.

In the previous chapters I have shown that it is impossible for a normal-sighted six-unit person to see more than six colours. If only pure colours—that is, colours reflecting the corresponding rays of the spectrum, had to be dealt with, the subject would present comparatively little difficulty. But very few colours in nature are pure; thus, a piece of blue-green glass, when examined with the spectroscope, is found to be transparent to the violet, blue, and green rays.

It is unnecessary to do more than allude to the results which have been obtained by such crude experimental methods as mixing pigments. These methods are useless, because we do not know what is the exact composition of the component colours.

With regard to the combination of spectral colours. This is a great improvement on mixing pigmentary colours, because we know the exact composition of each component. There is, however, a source of fallacy which I do not think has been pointed out, and that is the possible alteration in the colour by the surface from which it is reflected. The surface from which the colour is reflected might partially absorb one of the component colours. The least fallacious method of arriving at the composition of a compound colour is to examine the light which

is transmitted through a transparent coloured substance. In this way we not only arrive at the composition of the colour of the substance, but we are able to find out the result of the combination of two or more colours. The transmitted light may be examined with a spectroscope. Glasses, when properly analyzed, may themselves be used for the purpose of analyzing colour. Thus, if we have a blue-green glass which is found to be perfectly transparent to the violet, blue and green, and opaque to the other half of the spectrum, we can at once see whether there is any violet in a given red. If the colour be a pure red, when viewed through the blue-green glass it will appear perfectly black, but if the red contain any admixture of violet rays these will be visible.

Before discussing the composition of certain coloured substances in detail, I will give the results of my experiments with pure spectral colours. These were made with a very ingenious apparatus, constructed by Dr. Hoffert, which overcomes the possible source of fallacy I have mentioned. The electric light is used, and the brilliancy of the light can be diminished or increased at will. The coloured light enters the eye without the intervention of any substance. The observer looks through the eye-piece, which is only a narrow slit, directly at the prism. The source of light being movable, any portion of the spectrum may be brought in turn before the eye-piece. There are three electric lights, so that any two or three colours may be combined. A full description of this excellent apparatus will be found in the *Philosophical Magazine* for August, 1884.

The first fact which is apparent on mixing colours in this way is, that unless the colours are of very similar intensity no definite change is made in the predominant colour. In the following experiments, unless otherwise

stated, the colours were as nearly as possible of similar intensity. When the extreme red is combined with the other colours successively, no definite change is produced until the blue is reached, then the colour shows a shade of purple which increases up to the violet.

A bright red, combined with an emerald green (the centre green of the spectrum), gives a very fair yellow. If the green predominate the colour is greenish white. If the red predominate the colour is pink. Red and yellow-green give a brighter and more yellowish green. Yellow and red make a very fair orange.

Blue-green mixed with red gives a purplish white. If the green be moved towards the green the colour becomes green; if towards the blue the colour changes to purple.

Blue mixed with red gives purple, which is more marked as the violet is reached. Blue mixed with yellow makes white. The colours which give white are the most characteristic of each—namely, the purest blue and the purest yellow. On moving the blue into the green the colour becomes yellowish green. On moving the blue into the violet, the colour is first pinkish white, then yellow, owing to the feeble intensity of the violet. Besides being the purest colours, the yellow and blue were of similar luminosity. The white produced was more intense than either of the colours, and very pure. On moving the yellow towards the green the colour changes to blue without a trace of green, and remains so until blue is reached. Therefore, the combination of a green and a blue of apparently equal intensity, instead of making a blue-green, makes a blue of a brighter and lighter colour, without a trace of green. Under no circumstances could I obtain a definite blue-green. A green of greater intensity was absorbed in a feebler blue. When violet was put as a

contrasting colour next to the compound of blue and green, the colour appeared of a faintly greenish shade, a turquoise blue. On moving the yellow towards the red, the colour becomes pink, then purple. Blue and orange combine into a pink. Violet and yellow also make a pink. Violet and yellow-green make a white. On moving the yellow-green towards the red the colour becomes pink, then purple. On moving the yellow-green towards the blue the colour becomes faintly green at first (junction of green and yellow-green), and blue afterwards. Violet and orange make a pink.

With regard to the combination of three colours. Violet and red make purple; emerald green added to this makes white. On moving the green towards the red the colour becomes first green, then yellow. On moving the green towards the blue the colour becomes violet. When in the combination of purple and green, making white, the violet was shut off, the resulting colour made by the emerald green and red was yellow.

With regard to the combination of a green with a purple which is made with a feeble violet. The resultant is yellow, and is attained at the same point as before—namely, at the emerald or centre of the green. On moving the green to the red the colour becomes first green, then yellow at the yellow-green. On moving the green to the violet the colour is first pink, and then becomes more and more purple.

It is impossible to make a violet by combining any of the other colours of the spectrum. Blue and red, when combined, make a purple, and under no circumstances make a colour which resembles the violet of the spectrum. The addition of red to blue gives this colour a warm appearance, which is quite different from the cold violet of the spectrum.

The other method to which I have referred, namely that of ascertaining the composition of transparent substances (glasses or solutions) with the spectroscope, may now be considered. In this way we are able to get over the apparent source of fallacy which might arise from the nature of the body from which the coloured light was reflected. Thus, in the case where spectral light is combined upon a screen, we have to take into consideration the influence which the screen might have upon the colour. I have already shown that it is not necessary to have the whole of the rays of the spectrum in order to make white light. Therefore a substance might be perfectly white, and yet absorb many of the rays of the spectrum. When coloured glasses or solutions are examined with a spectroscope, the light passes directly through the instrument to the eye. If we have a glass which is purple in colour, and, on analysis with the spectroscope, find that the glass is opaque to all the rays of the spectrum with the exception of the green and the red, it is obvious that green and red make purple. Even in this method of testing the composition of a coloured substance there is a source of fallacy—namely, the alteration or absorption of some of the constituents of the coloured light in their passage through the glasses of the spectroscope.

When the composition of the colour of a glass is known, it can be used to find out whether there is any of a certain colour in the light reflected by an opaque substance.

The following is the composition of the Light Red glass used in the Classification Test. The glass is transparent to the red, orange, and yellow. It is nearly opaque to the violet, only that portion which is adjacent to the blue being seen. There is a dark absorption band, commencing at the junction of the yellow and green, and occupying

about one-fourth of the green. The green at the region of the blue-green junction is obstructed to a certain extent; the remainder of the green is visible as a bright band.

For an analysis of the light transmitted through the other glasses used in the Classification and Lantern Tests, see the Chapter on "The Tests for Colour-Blindness."

CHAPTER VIII.

THE PHYSIOLOGICAL PHENOMENA OF COLOUR.

A THEORY of colour-perception, in addition to explaining the phenomena of colour-blindness, must explain the physiological phenomena of colour. The theory of psycho-physical perception does this in a very complete manner, the phenomena being a necessary accompaniment of this theory.

In reading about the physiological phenomena of colour I found the most contradictory statements with regard to facts. Chevreul makes all these phenomena consistent with the red-blue-yellow theory of Brewster, and the supporters of the red-green-violet theory give the facts as corresponding in every way with this theory. It is obvious that both sets of facts cannot be true. On going through the various experiments I found that the facts as stated by Chevreul were in nearly every case correct, though his explanations are erroneous. On looking over his book it will be noticed that he was aware of facts which were inconsistent with his views. Thus, when talking about the complementaries, he, wishing to prove that, two complementaries being contrasted, the only effect is a change in intensity, says with regard to Orange and Blue, "Blue, the complementary of orange, being added to blue increases its intensity. Orange, the complementary of blue, being added to orange, increases its intensity." He then adds as a note, "Upon

repeating these observations with a deep blue and an orange which is not too red, the two colours appear commonly to become redder." I agree with the fact stated in this note. I have contrasted many blues and shades of orange, and the invariable result has been that they both appear to become redder. I have shown these pairs of colours to other persons, and their observations have agreed with mine. But what do the supporters of the Young-Helmholtz theory say with regard to these two colours? They also declare that colours differ on simultaneous contrast by the addition of the complementary. But their complementaries differ from those of Chevreul, and so the results will not be the same. Thus yellow, the complementary of blue, being added to orange makes this colour orange-yellow; whilst green-blue, the complementary of orange, being added to blue makes the latter incline to green-blue. That is to say, the predictions of each theory are opposed, and the facts agree with neither. It must be obvious to the reader that, if the facts were as stated by the supporters of the Young-Helmholtz theory —namely, that colours on being contrasted differed from each other by the addition of their complementaries they would be easily explainable by a theory of perception of difference, the explanation being that on contrast they became more unlike. But the facts are not consistent with this view, and so I had to repeat the whole of these experiments. Before discussing the various well-known phenomena of contrast, I will refer to the various sources of fallacy which I found in making my experiments.

1. *Colours to be contrasted must not be placed so that reciprocal absorption can take place.* Chevreul, in his excellent book, describes the different methods by means of which he obtained various greens by combining blue and yellow threads. He says that the first essential in

combining threads in this way is that the yellow and blue threads must contain little or none of the third primary colour (red), or else the brilliancy of the green will be impaired. The colour obtained in this way is produced by the absorption of the yellow and blue, and the reflection of the common factor green. In making these experiments, therefore, the contrasted substances must be placed so that reciprocal absorption cannot take place.

2. *The contrasted colours should not be very small.*—The reason of this is, that if the contrasting surfaces be very small an opposite effect will be produced, through the rays from both substances falling on one nerve-fibre. I made a series of experiments to prove that this was the case. I made a mosaic of small pieces of coloured cardboard, each piece being about half an inch long, and one sixteenth of an inch wide. The mosaic was made of the two colours placed alternately. The effect in every case was that the colours appeared as if the contrasting colour had been added to it; for instance, in combining blue and green in this way, the green appeared to have a shade of blue, and the blue appeared to have a shade of green. In combining blue and yellow in this way both appeared grayer, there was no tinge of green in either.

The subject may be considered under the following heads:—

1. Complementary Colours.
2. After Images: (i.) Positive, (ii.) Negative.
3. Simultaneous Contrast.
4. Successive Contrast.
5. Irradiation.
6. Colour Fatigue.

1. Complementary Colours.—There are certain pairs of colours which, when mixed, give rise to a sensation of white. These colours are said to be complementary to

each other. The complementary of red is blue-green; that of orange, greenish blue; that of yellow, pure blue; and that of yellow-green, violet. The complementary of pure green is not a simple colour, but a mixture, namely rose. The complementary colours may be best examined by means of a polariscope, and thin slices of selenite of different degrees of thickness. On viewing one of these plates of selenite we shall obtain a uniform field of colour. For instance, if we examine a plate of selenite giving a field of red, on rotating the prism of the polarizer the following phenomena may be observed. The point at which the field of red is brightest having been obtained, on rotating the prism the red becomes of less and less intensity. When the prism has been rotated through 45°, the field will be white. On continuing the rotation of the polarizer the complementary colour of red, blue-green, will come into view. This blue-green will be brightest when the prism has been rotated 90° from the starting-point. The rotation being continued, at 135° from the starting-point, the field is again white. On continuing the rotation the red again appears, and increases in intensity until the point of maximum intensity is reached at the starting-point. These colours can be shown to be exactly complementary to each other. The cause of the production of these complementary colours now remains for consideration. In accordance with the theory of psycho-physical perception, the normal-sighted will perceive any mixture of colours as a unit, a modified unit, or as white. It is, therefore, not surprising that the mixture of two colours representing the whole of the spectrum should make white. The complementary of any colour can be obtained by the subtraction of the colour itself from white light. It therefore follows that the complementary of any colour consists of a mixture of

the remaining rays of the spectrum. The position of the complementary corresponds for all persons, with a spectrum of normal length, though it is differently interpreted according to the colour-perception of the individual.

The following is a list of true spectral complementaries:—

Red	Blue-green
Orange	Green-blue
Yellow	Blue
Yellow-green	Violet
Green	Rose

2. **After-images.**—After-images may be of two kinds—Positive or Negative. The following will illustrate these phenomena. If we gaze very intently at an object of a red colour, and then look at a sheet of white or gray paper, we shall see an image of the object upon the paper, but of the complementary to orange, namely green-blue. Positive after-images are produced by gazing at a bright object for a short time, and then shutting the eyes. The after-image will be of the same character and colour as the object which gave rise to the sensation. It is therefore only a continuation of the original sensation.

A point in connection with the colours of negative after-images, which does not appear to have received proper consideration, is that the colour of the after-image is not the true complementary of the colour which has been looked at. For instance, the after-images of some coloured cards were as follows:—

Deep Red	Greenish Blue
Deep Yellow	Violet
Green	Rose
Blue	Orange
Rose	Green
Greenish Blue	Red
Violet	Yellow
Orange	Blue

The reason of this will be clear after reading the remainder of this chapter.

The following are the results of a numerous series of experiments, made in order to determine the changes which take place in the colour of the after-images obtained by gazing at the sun.

1. An after-image is rarely seen unless looked for, or the sun is directly looked at. Thus we may walk along a country road with the sun shining directly in our faces, and see no after-images, the attention being directed to other matters; but I have found, when reflecting on the nature of after-images, that it is very difficult to prevent myself from seeing them if the sun be shining at the time.

2. The after-image is much more persistent if looked for and carefully observed, than it is if no attention be paid to it.

3. The following are the changes which take place in the colour of the after-image, the bright sun having been looked at for a second, and then the eyes turned towards the blue sky, and the after-image watched until its disappearance, the eyes being kept open the whole time.

First a positive yellow image of the sun is seen, surrounded by pure green. The whole then changes into pure green; which becomes blue-green, then blue, then violet, and then very dark (black). A red element then comes in, and the after-image becomes purple, and then gradually fades away.

The same result is obtained with one or both eyes.

4. The left eye being shut, the sun is viewed with the right eye. This eye is then shut, and the left eye opened. An after-image is seen with the left eye.

5. The purple after-image is very persistent. If the attention be occupied with another subject for a minute

or two, and then the sky be looked at, an orange after-image will be seen. This on being looked at rapidly changes into purple.

6. When the attention has been diverted from the after-image for some little time, and it be then looked for, it will be found to be yellow. If the eye be now closed, a bright blue image will be seen, surrounded by a pure green halo. On opening the eyes the yellow image is again seen, but surrounded by a purple halo. If the eyes be now shut, a blue and green image as before will be seen.

7. If the previous experiment (No. 6) be carried out with one eye only, the other being bandaged, and the yellow images (there may be a number) looked at, and then the right eye closed, and the left eye opened, the after-images will be seen. They will have the same size, number, and arrangement, but will be bright blue instead of yellow. This blue rapidly fades away.

8. The colour of the after-images varies with that of the background.

9. If the eyes be closed any time when the purple after-image is visible, a pure green will be seen.

10. When several after-images have been obtained, and are of a purple colour when viewed against the sky, they appear pure green when seen against a black background.

11. If the eyes be closed before the purple after-image has been obtained, blue surrounded by green will be seen.

12. If the sun be not very bright, as on a misty day, the after-image appears as pure green. This gradually fades into gray. It is not surrounded by any colour, and does not change colour.

13. If the sun be looked at, and the eyes shut, the following changes take place in the colour of the after-

image. First, yellow surrounded by green, then blue-green, then blue, then violet, then blue, then blue-green, then green, then yellow-green, and then, if the hand be put over the eyes so as to give a black background, yellow.

14. When the eyes are shut, the colour of the after-images varies according as the eyes are simply closed or closed and covered with a handkerchief, so that the background is absolutely black.

15. The colours vary according to the brightness of the sun on the day of the experiment.

16. The following is the result of an experiment with a moderately bright sun, the eyes being simply closed. The after-image was first green, then green surrounded by violet, then blue surrounded by violet, then blue surrounded by purple, then green-blue surrounded by red, then blue-green surrounded by purple, then green surrounded by purple, then yellow-green surrounded by purple, then yellow surrounded by purple. The after-image then became colourless and faded away.

17. The change in the colour of the after-image varies according to the duration of the primary stimulus. The following four experiments were made with a moderately bright sun. The sun having been observed for a second, the eyes were closed and covered with a handkerchief, so that the background was absolutely black.

(i.) The after-image was first green, then violet, then blue, then green surrounded by purple, then yellow surrounded by purple, then orange surrounded by purple, then red. It then faded away.

(ii.) The after-image was first green, then blue, then green-blue, then blue-green, then green, then yellow, then blue. It then faded away.

(iii.) The after-image was first green, then blue sur-

rounded by violet, then blue-green surrounded by red, then green surrounded by purple, then blue surrounded by purple. The blue then appeared to merge into the purple, the whole becoming purple and gradually fading away.

(iv.) The after-image was first green, then blue surrounded by violet, then all violet, then blue, then green surrounded by purple, then yellow surrounded by purple; then the purple edging gradually encroached upon the yellow until nearly the whole was purple, the yellow remaining as a faint spot in the centre; the purple then became surrounded by blue, and then the image gradually faded away. The handkerchief was then taken away (the eyes being kept closed), and the image returned as a green disc against the red background. On opening the eyes, and looking at the sky, the image became yellow.

18. The second green mentioned in the above experiments (17, i., ii., iii. and iv.) having been obtained, the handkerchief was taken away, the eyes being kept closed. The green at once became blue.

3. Simultaneous Contrast.—The phenomena of simultaneous contrast have been worked out very extensively by Chevreul. He, however, adopted the red-yellow-blue theory, and considered that the differences of simultaneous contrast may be expressed by saying that the complementary of each colour was added to the opposite one. But the complementaries are not those given by him. Thus the complementary of red is blue-green, not pure green. The complementary of blue is yellow, not orange. The complementary of purple is green, not yellow. It is obvious, therefore, that the changes produced by simultaneous contrast are not those suggested by him.

The following contrasts are based on observations made with Dr. Hoffert's apparatus for mixing spectral colours.

In this way the changes which pure spectral colours undergo when compared are evident. I have made numerous experiments with pigmentary colours, and find that in nearly every case the change undergone by a pigmentary colour corresponds to that with a spectral colour. I have a book which I constructed to show the change which pigmentary colours undergo when contrasted. Each page contains one colour shown upon a white surface and on coloured surfaces. The observations with spectral colours are, however, incomparably more important, as it is impossible to reason upon mixed colours until the changes which pure colours undergo have been definitely determined.

Though Dr. Hoffert's apparatus was not constructed with a view to ascertain the phenomena of simultaneous contrast, it is admirably adapted for the purpose. The apparatus is constructed so that two colours, either pure or mixed, are seen side by side, all other light and colour being excluded.

The following are the changes which are met with in simultaneous contrast.

A light colour being contrasted with a dark colour, the light colour appears to become lighter, and the dark colour appears to become darker.

The following pairs of colours being contrasted—

Red	becomes more intense
Blue-green	inclines to Blue
Orange	„ Red
Green-blue	„ Blue
Yellow	„ Orange
Blue	„ Violet
Yellow-green	„ Yellow
Violet	becomes more intense

Green	...	...	...	becomes more intense.
Rose	...	...	...	" " "
Red	...	...	...	inclines to Rose-red
Orange	...	...	...	" Yellow
Red	...	...	...	" Rose-red
Yellow	...	...	...	" Green
Red	...	...	...	" Rose-red
Yellow-green		...	...	" Pure Green
Red	...	...	...	becomes more intenso
Green	...	...	...	inclines to Blue-green
Red	...	...	...	becomes more intense
Blue	...	...	...	inclines to Violet
Red	...	...	...	becomes more intense
Violet	...	...	...	" " "
Orange	...	...	...	inclines to Red
Yellow	...	...	...	" Green
Orange	...	...	...	" Red
Yellow-green		...	...	" Green
Orange	...	...	...	" Red
Green	...	...	...	" Blue
Orange	...	...	...	" Red
Blue-green		...	...	" Blue
Orange	...	...	...	" Red
Blue	...	...	...	" Violet
Orange	...	...	...	" Red
Violet	...	...	...	becomes more intense
Orange	...	...	...	inclines to Yellow
Rose	...	...	...	" Violet
Yellow	...	...	...	" Orange
Yellow-green		...	...	" Green
Yellow	...	...	...	" Orange
Green	...	...	...	" Blue

Yellow ...	...	...	inclines to	Orange
Blue-green	...	...	"	Blue
Yellow ...	...	...	"	Orange
Violet ...	...	...	becomes more intense	
Yellow ...	...	...	inclines to	Yellow-green
Rose ...	...	...	"	Violet
Yellow-green	...	...	"	Yellow
Green	...	...	"	Blue
Yellow-green	...	...	"	Yellow
Blue-green	...	...	"	Blue
Yellow-green	...	...	"	Yellow
Blue ...	...	...	"	Violet
Rose ...	...	...	"	Violet
Red ...	...	...	"	Orange
Green ...	...	...	"	Yellow-green
Blue-green	...	...	"	Blue
Green ...	...	...	"	Yellow-green
Blue ...	...	...	"	Violet
Green ...	...	...	"	Yellow-green
Violet ...	...	...	becomes more intense	
Blue-green	...	...	inclines to	Green
Blue ...	...	...	"	Violet
Blue-green	...	...	"	Green
Violet ...	...	...	"	Purple
Blue-green	...	...	"	Green
Rose ...	...	...	"	Red
Blue ...	...	...	"	Green
Violet ...	...	...	"	Purple
Blue ...	...	...	"	Green
Rose ...	...	...	"	Red
Violet ...	...	...	"	Blue
Rose ...	...	...	"	Red

With compound colours, of a composition rarely met with in nature, the changes were similar to the deduction of the colour on the contrasting side. The changes were more marked than with simple colours. For instance, a compound yellow made by mixing red and green, on being contrasted with red and orange, becomes a decided green; on being contrasted with green or blue, the colour becomes a decided pink. This result is similar to that produced by the deduction of red on the one hand, or green on the other, from the compound colour. The compound yellow when compared with spectral yellow does not undergo any change in colour, but its compound character becomes more evident. It looks like a yellow, but not like a pure yellow. A white made by mixing yellow and blue becomes lavender when contrasted with green, violet when contrasted with red, orange, or yellow.

It will be seen that the only pairs of colours which do not alter in hue when contrasted are green and rose, and red and violet. The other colours alter as follows: When both colours lie within the spectrum, and neither are terminal units (that is red or violet) each colour appears as if it were moved more towards the end of the spectrum furthest away from the other colour. When a terminal unit is contrasted with other spectral colours it appears as if the other terminal unit had been added to it if the contrasting colour be one lying between it and the centre of the green. If the contrasting colour is situated at a point further from the terminal unit than the centre of the green the terminal unit will not change colour, but the contrasting colour will appear as if it were moved more towards the other terminal unit. The change of colour in simultaneous contrast is always greatest with colours occupying closely adjacent positions in the spectrum scale. The effect of contrasting blue-violet with violet, or orange-

red with red is greater than that of contrasting any other spectral colour with the terminal units. The effect of contrast is in direct proportion to the nearness of the colours.

When pigmentary colours are contrasted with white or gray, the latter changes in colour as follows :—

Deep Red	Greenish Blue
Orange	Blue
Deep Yellow	Violet
Green	Rose
Greenish Blue	Red
Blue	Orange
Violet	Yellow
Rose	Green

In the first column are the names of the colours contrasted with white.

4. Successive Contrast.—If we look at a number of blue-green pieces of cloth and then at a piece of red cloth, the latter will appear of a much more brilliant colour than it would have appeared if it had been the first piece of cloth shown. Similar changes are experienced with other colours.

The results obtained by successive contrast are similar to those obtained by simultaneous contrast, only they are more satisfactory and decided. The method I adopted was as follows. With a selenite slide and a polariscope I was able to obtain definite colours. Then, after looking at a field of one colour for a short time, I looked at a field of another colour and noted the appearance of the latter. After waiting a few minutes I noted the real colour of the field. The effect of the contrast of red and blue was very marked, even when a red inclining to rose was employed. I looked at a field of red for several minutes until the red appeared nearly black from colour-fatigue. I then changed the field to one of pure blue. The first effect was as if a cloud of greenish blue passed across the field, immediately disappearing, and leaving a

field of violet. This field of violet was very much paler than the blue at which I was really looking.

5. **Colour-Irradiation.**—If a small patch of coloured material lying on a white ground be gazed at for a short time, the ground will be tinged of the colour which would appear by simultaneous contrast.

6. **Colour-Fatigue.**—If a colour be looked at for some time the eye and brain will be less sensitive to that colour than to other colours, and will be most sensitive to its complementary. It is well known to drapers that a red cloth will appear much more brilliant if some green cloths have been previously exhibited.

I have given the facts of the physiological phenomena of colour as I myself see them. It will be noticed that these facts differ in many respects from those given by the supporters of the red-blue-yellow theory on the one hand, and those of the red-green-violet on the other. It is curious to notice how these facts differ. The chief point in which the facts above stated differ from those recorded is that of the simultaneous contrast of blue and red. It will be noticed that I have stated that when blue is contrasted with red the blue inclines to violet, and not to green as stated by others. I must confess that I was rather surprised to find this result, as I saw no reason to question the view that in simultaneous contrast the colours differed by the addition of the complementary. It will be noticed from the theory of the perception of difference that the addition of the complementary would increase the differences between colours as much as possible. But we must not regard the colour series as a circle. It is evident that this series is physiologically a straight series, and that the violet waves differ from the red more than the blue-green ones do. When violet is contrasted with red both become brighter.

The explanation of simultaneous contrast must be considered apart from complementary colours. The phenomena are most marked when the colours contrasted correspond to near positions in the spectrum. The theory that each colour differs by the addition of the complementary of the other would not explain the differences, because the contrast would be greater in cases in which the colours were not so closely allied. To take as an illustration a pure yellow and a yellow tinged with green. The complementary of yellow, namely blue, added to the greenish yellow, makes a greenish white. The complementary of greenish yellow is a blue differing very little from a pure blue, being inclined towards violet-blue. The addition of this complementary to the pure yellow would make it white, tinged with blue. Whereas the effect of contrasting the two colours is that the yellow inclines to orange, and the greenish yellow to yellow-green.

Again, let us take yellow and green and contrast them. It is obvious that the complementaries of these two colours differ much more than those of greenish yellow and yellow. Thus the complementary of yellow, namely blue, added to green makes blue-green, whilst the complementary of green, namely rose, added to yellow makes pink. Now, yellow and greenish yellow differ much more markedly when contrasted than yellow and green do.

The phenomena of simultaneous contrast must be considered purely as measuring the differences between colours. When one colour is contrasted with another the difference between the two becomes more marked—that is to say, the lower colour apparently occupies a position a little lower down the scale, and the higher colour a position a little higher up the scale. The closer the positions occupied by colours on the scale the more marked the differences become. We have to consider the

effect of the modified unit purple. Does a blue contrasted with a violet make the latter appear more purple? It is obvious enough that if once an element of red be admitted in the violet the colour is no longer a true violet, but one of the modified units between violet and red. But the contrast of blue with a violet which has or has not an element of red will make that colour incline to red. This does not make the colour series a circle, but is simply due to the fact that the unit red is capable of combining with the unit violet, to give rise to the modified unit purple.

The question now comes for consideration. Are these phenomena due to changes in the retina, or to changes in the brain? I am inclined to think that the phenomena are partly retinal and partly cerebral, and the following experiments give support to this view.

1. A definite complementary, having the shape of the object looked at, may be seen even if the eyes be kept moving during the whole of the experiment, so that the coloured object shall occupy respectively every portion of the visual field. The complementary is not so vivid as that produced by a fixed gaze.

2. If we look intently at a coloured object with the left eye, the right being bandaged, and then suddenly close the left eye and look at a piece of white paper with the right eye, a complementary will be seen. This will be of a less intense character than if seen with the left eye.

3. If we bandage the right eye and obtain a complementary with the left, on looking at this complementary for a short time, and then closing the left eye and looking at a piece of paper with the right, we shall see an after-image having the colour of the original object.

A careful consideration of the facts given above will show that they may be classified under two heads:—

1. Those due to psycho-physical perception.

2. Those due to colour-fatigue of the retina and brain.

The first class includes all those changes in which the colour appears to be shifted to a higher or lower point in the colour-scale. The second class includes all those changes in which a complementary colour is apparently seen. The changes in all cases are greater when both effects are combined, and least when they are opposed. As an instance of this, let us take a series of coloured cards and put a small piece of gray paper on each. It will be noticed that the greatest effect is produced on the green and rose cards, the gray paper in each case being tinted of a decided rose or green, according to the colour of the card. Again, the least effect is produced in the case of the red and violet cards. In the case of these latter, it is difficult to detect any alteration in the colour of the gray. In the case of the green and rose cards, both factors tend to make the gray appear tinted with the complementary colour.

The explanation of complementary colours by my theory of retino-cerebral perception is as follows. When the colour-perceiving centre in the brain has just been perceiving rays of a certain kind, it and the retina are directly afterwards less responsive to those rays than to rays of a different degree of refrangibility, and so surrounding objects will appear to be deficient in that colour. For instance, if a person has been looking at a red object and then looks at a piece of white paper, the perceptive centre not being actively responsive to the red rays, the white appears to be deficient in the red, and is perceived as blue-green, which is the colour obtained by mixing the remaining rays of the spectrum. As I have previously stated, the blue-green seen will not be the true complementary of red, but a much bluer colour, really a greenish blue. This is due to contrast.

CHAPTER IX.

OBJECTIONS TO PREVIOUS THEORIES OF COLOUR-PERCEPTION.

A CONSIDERATION of the facts which I have given, shows that neither the Young-Helmholtz nor Hering's theory of colour-perception will explain the phenomena of colour-blindness in a satisfactory manner.

With regard to the former of these theories, Helmholtz modifying Young's theory of colour-perception, assumes that there are in the retina three sets of nerve-fibres, the stimulation of the first set giving rise to the sensation of red, of the second the sensation of green, and the third the sensation of violet. He assumes that all kinds of light stimulate all three sorts of fibres, but in a different proportion. The following diagram shows the proportional stimulation of each set of nerve-fibres by different varieties of pure light.

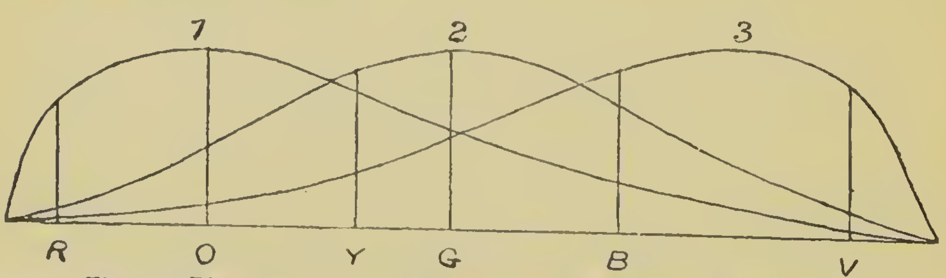

Fig. 12.—Diagram of the three primary colour-sensations. (Holmgren.)

No. 1 curve corresponds to the red set of fibres, No. 2 to the green set, and No. 3 to the violet set. The height of the curve represents its proportional stimulation by

the variety of light indicated by the letter. Thus pure yellow light stimulates the red and green sets of fibres considerably, and the violet set slightly, the resulting sensation being yellow.

Holmgren has applied this theory to the phenomena of colour-blindness. He divides the colour-blind into the following classes :—

A. Total colour-blindness, in which only one set of fibres is present in the retina, and so the individual can only perceive colours as varying degrees of light and shade.

B. Partial colour-blindness, in which one set of fibres is completely absent. There may be three varieties :—

(i.) Red-blindness.

(ii.) Green-blindness.

(iii.) Violet-blindness.

C. Incomplete colour-blindness, in which one or more of the three sets of fibres are defective.

The following objections may be urged against this theory :—

1. Perception of Shade.—First with regard to those cases which have been classed under the heads of complete red-blindness, complete green-blindness, and complete violet-blindness.

If one set of fibres, responding variably to rays of light of different degrees of refrangibility, were removed, it ought to follow that the perception of light and shade of a colour-blind person should differ from the normal in a corresponding degree. Thus we can represent either of the above varieties of colour-blindness by the preceding diagram, with the corresponding curve removed. In the case of red-blindness we should remove the red curve, green-blindness the green curve, and violet-blindness the violet curve. This, according to Holmgren, gives us a key to the colour-perception of the colour-blind.

Let us take the first and, according to Holmgren, the commonest variety of colour-blindness, namely red-blindness, in which the red set of fibres is supposed to be absent. Then all colour sensations will be made up of green and violet, the junction of the two curves being at the blue-green. Aeeording to this theory, spectral red will exeite the green perceptive slightly, and the violet pereeptive still more faintly, the resulting sensation being a green of very feeble intensity. Spectral green will excite the green perceptive to its maximum degree of stimulation, and the violet perceptive eonsiderably, the resulting sensation will therefore be a very bright green. From this we should expect that the colour-blind who had been diagnosed as being red-blind, would mateh a bright saturated red with a dark green. They would also match shades of orange and yellow with less saturated but darker shades of green.

This, however, is not the ease ; and for illustration we ean take a typieal ease of redgreen-blindness (a two-unit with a speetrum of normal length, without a neutral band in the green), and give him a large number of eoloured wools, there being a considerable variety of shades of red, orange, yellow, yellow-green, and green, and tell him to pick out those whieh are most alike in every respect, and, if possible, to find identical wools. It is necessary that the reds and greens should be pure—that is, refleet no violet or blue light,—because to the two-unit, violet and red, like blue and green, make a gray. It will then be found that the colour-blind will make matehes corresponding exactly to those of a normal-sighted person. Thus he will match a red of a certain shade with a green of a corresponding, and not a darker shade. The same with the shades of orange and yellow-green.

The fact that many colour-blind persons are able to

match shades of colour very accurately has been stated by many writers.

Nichols* has made many experiments in order to test the sensitiveness of the eye to colours of a low degree of saturation, and the perception of shade. He found that colour-blindness does not affect to any marked degree a person's ability in this respect.

The immense importance of this fact, as a proof that the Young-Helmholtz theory is a fallacy, does not appear to have been recognized, or, as far as I am aware, even mentioned. Colour-blind persons would make very poor engravers if they represented a light red as black. When it is considered what a very considerable effect upon the perception of shade, even a slight shortening of the spectrum has, the effect of the subtraction of one-third of the light-perceiving fibres, would have an effect upon shade which could not be overlooked. The following diagrams (Figs. 13, 14, 15) show the marked effect upon the perception of shade which the subtraction of one set of fibres would have, according to the Young-Helmholtz theory. The curves should be compared with those constructed by Captain Abney and Major-General Festing. It will be seen that, whilst the shade of any given green is not altered to any great degree, reds must appear very dark indeed.

We can put this objection in the form of a mathematical proposition constructed from the diagrams.

Let A equal the amount of light which the brain receives through the red set of fibres, B that received through the green set of fibres, and C that received through the violet set of fibres. Let the curve A be removed.

* "On the Sensitiveness of the Eye to Colours of a Low Degree of Saturation:" Edward L. Nichols, Ph.D., *American Journal of Science*, vol. xxx., p. 37.

Then spectral red will have lost seven-eighths of its luminosity, only one-eighth of the retinal stimulation perceived by the normal-sighted taking place. But

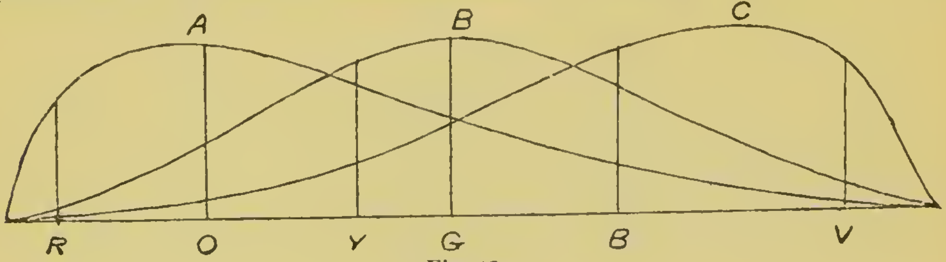

Fig. 13.

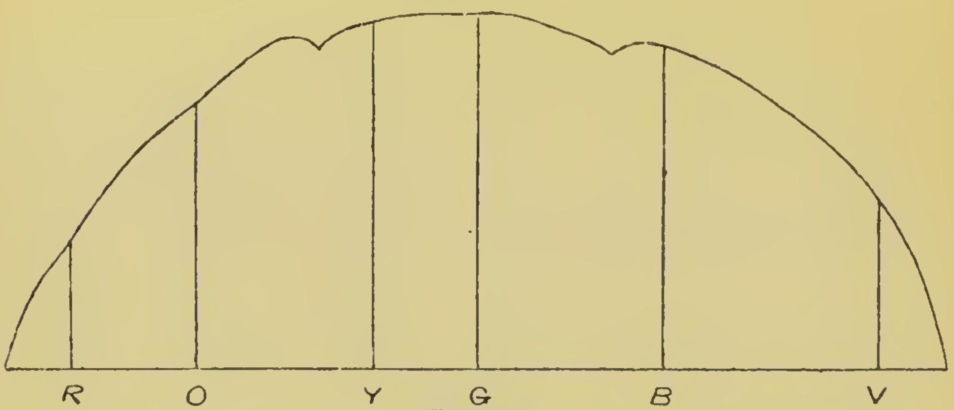

Fig. 14.

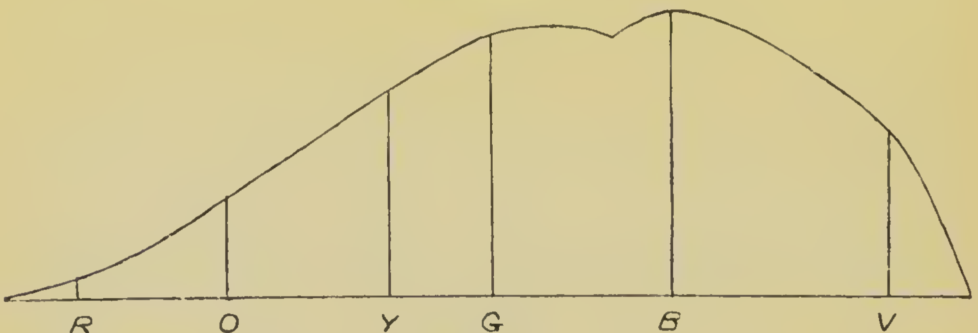

Fig. 15.

Fig. 13 is the diagram representing the three primary colour-sensations of the Young-Helmholtz theory.
Fig. 14 is a luminosity curve for a normal sighted person, constructed from the above diagram.
Fig. 15 is a luminosity curve for a red-blind, constructed from the above diagram.

spectral green only has its luminosity diminished one quarter. Therefore, if the red and green have been

adjusted so as to appear similar in shade to the normal-sighted, they must appear dissimilar in shade to the red-blind, because if unequals be taken from equals the remainders cannot possibly be equal. But on examination a redgreen-blind is found, who says that the two colours are identical in every respect, both in colour and shade; that is to say, unequals being taken from equals equal remainders are left, which is absurd. Therefore the theory is untrue.

This proof appears to me so conclusive that, if the Young-Helmholtz theory had not received the support of men of great ability, I should have rested content with the above objection, the difference in the subtraction being so great, that its effect upon shade could not have escaped notice, even with the roughest examination, far less with careful examinations directed specially to this point. Out of respect, therefore, to those who have supported the theory, I will discuss in detail other objections which have occurred to me in the course of my investigations.

2. Varieties of Redgreen-blind.—If the Young-Helmholtz theory were true, there would be definite varieties of colour-blindness—namely, the red-blind in whom the red-perceiving fibres were absent, and the green-blind in whom the green-perceiving fibres were absent. But this division, which has been made by Holmgren, is quite artificial. Many observers have noticed that those who have been found to be red-blind at one examination have at another time been found to be green-blind.

Compare two diagrams, one with the green curve of the Young-Helmholtz theory removed, and the other with the red curve absent. It will be seen that the mistakes made in each case would be quite different. In the case of red-blindness a neutral band would be found in the

blue-green, whilst in green-blindness the neutral band would be found in the centre of the green of the spectrum. The position of the neutral band appears to depend entirely upon the length of the spectrum. When this is normal the neutral band is in the centre of the green. When the spectrum is shortened the neutral band is found correspondingly nearer to the unshortened side.

A redgreen-blind will be found to make the mistakes of both classes, and this is especially evident if he be set to classify a large number of coloured objects of different materials. He makes a classification in accordance with the two units he possesses, and the slight modifications met with are due to the presence of a shortened spectrum. or a neutral band.

3. Direct Evidence of Colour-blind Persons.—According to this theory, a colour-blind with the red-perceptive absent ought to see green as the most representative colour of the first unit; but the simple two-unit invariably say that yellow is the colour which they see, and, as they are speaking of spectral light, there can be no question about the purity of the colour.

Dr. Pole * says, referring to this theory: "This theory is in great favour owing to the eminence of its authors, and the support of many distinguished physicists. But objections have been raised to it on several grounds, one of the most forcible being that it does not accord with the experience of the colour-blind. If there is any one fact more unequivocally deducible from their evidence than another, it is that the less refrangible colour they perceive corresponds to yellow, and not to green. In my own case, which I believe is a typical one, my long-wave colour is most vivid and positive, and it is an absolute certainty that its maximum splendour is excited by the buttercup, or by the pigment Chrome Yellow, or by the sodium line;

* "Colour-blindness:" Dr. Pole *Nature* 1879, p. 479.

whereas objects that I hear called green give me no definite impression at all; sometimes they assume a debased, dirty, or washed-out buttercup-colour; sometimes they look black or gray, and sometimes they even give my opposite sensation, blue. How, therefore, it can be argued that my most brilliant buttercup sensation is excited by green objects rather than yellow ones, is to me unintelligible."

4. Variable Shortening of Red End of Spectrum.—The shortening of the red-end of the spectrum, which is occasionally very great, is not explained. This shortening is very variable, and is often not present at all. Thus, in the case of Dr. Pole, and many others whom I have examined, the spectrum was of the normal length. This shortening is not connected with the diminution in the number of the units. I have found considerable shortening of the red end of the spectrum in a four-unit colour-blind, and it may be met with in a person whose units are of the normal number. The shortened portion of the spectrum is not perceived at all; that is to say, the colour-blind says that the field is quite black when the portion of red or violet which he cannot perceive is present. Then the line of demarcation is quite abrupt, so how are we to explain this according to the theory? For instance, take a colour-blind who is able to perceive half of the red of the spectrum. How is it that the green and violet perceptives are able to respond to one half and not the other of the red? Also, how is it that the degree of shortening is variable?

5. Variable Shortening of Violet End of Spectrum.—The shortening of the violet end of a bright spectrum, which is often met with in both partial and extreme cases of colour-blindness, is not explained. In many redgreen-blind the violet end of a dull spectrum is considerably shortened. The violet perceptive being normal, how can

this be explained? It is not entirely due to the lessened intensity, because if a portion of violet more towards the middle of the spectrum be taken, and its intensity reduced until it is only just visible to the normal-sighted, the colour-blind will recognize it as well.

6. The Class of the Seven-unit.—The theory will not explain why certain persons can see seven colours in the spectrum.

7. Complementary Colours.—The fact that the two-unit colour-blind see the complementary colours in one unit, is a very strong point against this theory. The two-unit colour-blind do not see complementary colours as readily as the normal-sighted do, but, if the directions I have given be followed out, they will be able to see them. Under these circumstances we can obtain a complementary which corresponds to that seen by the normal-sighted. According to the Young-Helmholtz theory, if a red-blind saw a complementary of red at all, it should be blue; but I have only once received this answer. I have had two-unit colour-blind call the complementary of red, yellow and yellow-green, as well as those who have called it blue-green and pointed out the correct colour.

The theory will not explain the fact that complementary colours, which are obtained by looking for a short time at a coloured substance, are different from those obtained by mixing spectral colours. The former differ from the latter in being situated at a greater distance from each other in the spectral scale. Thus blue is the true complementary of yellow, but the coloured after-image obtained by looking at a blue object is orange. The after-image obtained by looking at a yellow object is tinted violet.

8. Simultaneous Contrast.—The phenomena of simultaneous contrast are not well explained by this theory.

The theory does not account for the fact that blue contrasted with red inclines to violet. According to the theory the blue should incline to green. The theory does not account for the fact that colours which occupy a closely adjacent position in the spectral series are more altered than those which are situated at a relatively greater distance.

With regard to shadows coloured by contrast. If we take a piece of ruby-red glass and interpose a pencil between it and a piece of paper, the paper will be coloured red by the transmitted light which passes through the glass. The interposition of the pencil will, however, cause a shadow to fall upon the paper. This will be tinged with the colour which would appear by simultaneous contrast. As the shadow will appear greenish blue directly it is looked at, the phenomenon cannot be due to over-stimulation of the red set of nerve-fibres. Besides, the portion of retina which receives the coloured shadow has not received the colour itself, and so its fibres cannot have become exhausted.

9. Successive Contrast.—The phenomena of successive contrast present similar difficulties.

10. After-images.—(i.) The fact that an after-image can be seen when the eyes are shut and all light excluded is not explained by this theory. (ii.) The fact that an after-image of a complementary colour is seen with an eye which has been kept closed, the coloured object having been observed with the other eye, is not explained.

11. Variations in Intensity.—The fact that we can see only three colours in a spectrum of lessened intensity, namely red, green, and violet, has been brought forward as a fact in favour of the Young-Helmholtz theory of colour-perception. As a matter of fact, it should be brought forward as a strong fact against this theory; thus,

why should the rays of light occupying the position of the D lines of the spectrum be seen as red? They ought, according to this theory, to be seen as a yellow of low intensity; because, whether the rays of light be many or few, they would equally stimulate the two primary sensations. I do not think that the theory accounts in a satisfactory manner for the presence of yellow and blue in the spectrum. The spectrum ought to have the appearance which it has to the three-unit—that is, the yellow should be replaced by reddish green. Why should a new colour, yellow, appear?

12. Colour-mixing.—There are many facts in the mixing of spectral colours which this theory will not explain, particularly the fact that red and green when mixed will make a pink, which is very similar to that made by mixing red and violet. It is true that red and green may be proportioned so that a yellow is obtained, but the fact that they make a pink has to be explained.

13. Structure of Retina.—The microscopic structure of the retina affords not only no evidence of there being three sets of fibres, but direct evidence that such is not the case. The evidence of the latest observers shows that the cones, as a whole, expand under the influence of one kind of light, and contract when submitted to another kind.

14. Colour-blindness through Hypnotism.—It has been stated by some hypnotists that colour-blind persons have, when under the hypnotic influence, been able to sort and arrange colours like normal-sighted persons; whilst many normal-sighted persons have been made temporarily colour-blind by hypnotism.

These experiments I have not yet confirmed, but I see no reason for doubting their accuracy. If true, they form important evidence against the theory. Hypnotism could not replace a congenitally defective set of nerve fibres,

but it is easy to understand how a concentration of nervous force might make a small faculty have temporarily the same influence as a normal-sized faculty has constantly, and so enable a person to distinguish between units previously alike to him. In the same way we can understand how the withdrawal of nervous force would diminish the function of a normal-sized faculty. We meet with analogous conditions of other faculties. Most persons are cognizant of the effect of hypnotism upon the emotional faculties.

15. Temporary Colour-blindness in Insanity.—Dr. Savage informs me that temporary colour-blindness is not uncommon in cases of insanity of an emotional-hysterical type. It seems to me very improbable that there is abrogation of function of one set of fibres in cases of this kind. The symptoms point to disorder of the brain.

16. Temporary Colour-blindness in Congestion of the Brain.—Bronner states * that congestion of the brain will cause a temporary colour-blindness. This plainly points to the brain as the seat of this affection.

II. With regard to Hering's Theory of Colour-perception.—This theory is not nearly as plausible as the Young-Helmholtz, and will not explain so many of the phenomena of colour.

Hering assumes that there are three substances in the retina which are variously acted upon by rays of light, being disintegrated by one colour and built up by another: first, a substance which is disintegrated by red and built up by green; second, a substance which is built up by blue and disintegrated by yellow; and, third, a substance which is disintegrated by white and the other dissimilative colours, and built up by black and the other assimilative

* "Colour-Blindness, Edward Bronner, M.D., *Medical Times and Gazette*, April 12, 1856.

colours. Hering says that the black-white substance is most acted upon by the yellow rays of the spectrum. The red-green substance is acted upon by three parts of the spectrum, red at each end, and green in the middle. The blue-yellow substance is acted upon by the whole of the spectrum with the exception of the green. It will be seen that spectral red acts upon the blue-yellow substance as well as upon the red-green substance, and that spectral violet also acts upon both substances. The only spectral colour which is capable of giving rise to a pure sensation of colour, according to this theory, is green.

1. Perception of Shade of Colour-blind Persons.—The arguments which were used with reference to the Young-Helmholtz theory equally apply to this theory, substituting 'chemical substance' for 'set of nerve-fibres.' When we find that there is no alteration in the perception of shade there can be no loss of importance of any light-perceiving substance.

2. Spectral Examination of the Colour-blind.—According to the theory a redgreen-blind should see spectral red and orange as yellow, and spectral green as white, but a redgreen-blind sees red, orange, yellow, and green as colours which in no way differ from yellow. Also, if a redgreen-blind person saw spectral red and orange as yellow, and spectral green as white, he would not confuse red and green. But he does confuse red and green, therefore the theory is fallacious.

According to the theory a blue-yellow blind should see spectral red and orange as red; spectral yellow and blue as white and black; spectral green as green, and spectral violet as red. I have not met with a colour-blind person who has seen the spectrum in the above way; and I am not aware of any recorded case in which spectral blue has been seen as black. From this it is seen that the theory

is inconsistent with the established facts of colour-blindness.

3. **Complementary Colours.**—There is no evidence to show that red and green, and blue and yellow are opposed. White and black may be opposed, and each of the colours may be opposed to black, which is the negative of white and of all colours. The simple colours are not complementary as Hering states, thus the complementary of red is bluish green, not green. The antagonistic colours of Hering do not annihilate each other, but combine into a white manifestly more intense than either of the colours.

It is unnecessary to discuss any further objections to this theory.

It may be well to consider the restrictions which facts put upon theory in connection with colour. From the fact that many colour-blind persons are able to match colours with regard to shade with perfect accuracy it is evident that there can be no loss of any light-perceiving portion of the retina. It is therefore evident that any theory which assumes this loss must be a fallacy. A retinal theory, to be consistent with this fact, must assume the existence of separate organs in the retina for the perception of colour and light. There are two separate organs in the retina—the rods and the cones; but then the rods are absent from the fovea centralis where the perception of light and colour are both most distinct. Then, as colour is not a physical property of bodies, it is very difficult to comprehend how it could exist apart from light. It is easy enough to understand how shortening of the spectrum might be due to some retinal defect, because, in this case, a certain number of rays are not perceived, and there is light as well as colour loss.

Deductions made from a few cases are useless, because

the essential facts cannot be separated from the individual details; thus I am not aware that any previous observer has separated shortening of the spectrum from colour-blindness due to defective perception, and until this is done the facts are very difficult to explain. Then, the colour may be modified by the media of the eye. From this it will be seen that it is necessary to obtain the details of a large number of cases, and note those facts which are common to all.

CHAPTER X.

THE CLASS OF THE SEVEN-UNIT.

I HAVE described the colour-perception of the normal-sighted, but there still remains a class who have a colour-perception different from the normal-sighted, and yet are not colour-blind. These persons see seven colours in the spectrum, and the division is different from that of the normal-sighted. See Fig. 1 of the frontispiece. The percentage of these persons is very small. There is probably not more than one in every two or three thousand. I have met with three cases. One was a mechanic, who was pointed out to me as colour-blind because he had persisted in calling a colour blue which his fellow-workmen all agreed in calling a violet. I examined him with the spectrum, and he marked it out as in Fig. 1. He persisted in saying that there was a dark blue visible between the blue and the violet, though I could see no definite colour at this point, neither was the spectrum particularly dark. This is, in all probability, how Newton marked out seven colours in the spectrum. He tells us that he and a friend of his, who was noted for having a particularly good eye for colour, obtained similar results. Newton would not have been likely to have marked out a colour which he could not see.

The seven-unit also see the orange band of a larger size than the normal-sighted.

Many become aware that they differ from the normal in this respect. Thus, when I was testing a man who possessed very accurate colour-perception, and whose occupation consisted in matching and arranging colours, I picked out a violet and asked him what colour it was. He said, "I should call it a blue; some people would call it a violet." I then picked up a very dark blue, and said, "Would you put it with this?" "No," he replied, "I should not; it is a distinct colour. People seem to class so many colours under one name."

All the persons I have found belonging to this class have been very fond of colours. The first individual whom I came across was an amateur artist, who, his employer told me, painted very well.

It is perfectly certain that individuals belonging to this class see more in colour than the normal-sighted. They can match colours with greater ease, and have a better memory for varieties of colour. They can also recognize differences in colour which are not perceptible to the normal-sighted. This we should expect, as their absolute psycho-physical units are smaller. In order to prove this increased power of colour-perception I constructed a test in the following way: I painted a ground of Prussian blue, and then, when the colour was dry, I put an after-tint of another colour over it, keeping a careful record of what I had done. In most instances I put the after-tint only over half of the disc. On looking at these coloured discs I am unable to tell, without referring to my note-book, the colour of the after-tint.

I took these discs to a well-known artist, but he failed to tell the colour of the after-tints. A pupil of his, however, a boy of fourteen, looked at the discs, and told the colour of the after-tint correctly in each case. He apologized for seeing the colours like this (because his

master was so incredulous), and said that he had something the matter with his eyes when a child.

I have also used squares painted with various mixtures of colours in order to test the seven-unit, with the same result. It is obvious that practically this class is of little importance, as they are able to recognize all the differences in colour which are perceptible to other persons, and they are able to recognize differences which are not perceptible to others. It is probably on this account that systems of colour nomenclature have found little favour, and there is not a definite system in general use. It will be noticed in Fig. 1 that the blue encroaches on the green of the normal-sighted. A seven-unit person would therefore call a colour a blue which a normal-sighted person would call a green. This is just the opposite to the mistakes of the colour-blind, who include a portion of blue in their green.

CHAPTER XI.

THE QUALITATIVE AND QUANTITATIVE ESTIMATION OF DEFECTS OF COLOUR-PERCEPTION.

Before discussing the methods which should be employed to ascertain the degree of colour-defect of a colour-blind person, it is necessary to consider in detail the causes of colour-blindness. These may be ranged under four heads.

I. Colour-defects due to absorption of certain rays by the media of the eye.

II. Colour-defects due to non-excitability of the visual substance or optic nerve-fibres by rays of light of a certain wave-length.

III. Colour-defects due to pathological conditions.

IV. Colour-defects due to imperfection of the colour-perceiving centre.

Each of the above subdivisions requires to be considered separately. On examining a case of colour-blindness, we must ascertain under which of the above heads the defects must be classed. We may meet with any one of the above conditions alone or combined, and it is this want of classification which has made the study of colour-blindness so difficult.

An examination with the spectrum should first be made to ascertain the psycho-physical perception of the individual examined, and whether there is shortening of

the spectrum for bright light, or light of diminished intensity.

With regard to the first class, namely, colour-defects due to absorption of certain rays by the media of the eye. I think that the importance of defects due to this cause has been very much exaggerated. The absorption is so slight in comparison with the quantity of light which enters the eye, that in the absence of any other colour-defect there would scarcely be any alteration in the appearance of colours. Again, the colour-perceiving centre would become less sensitive to impressions of the predominant colour, and more sensitive to those of its complementary. I have carefully looked for a case in which the whole colour-defect might be put down to absorption by the media of the eye, and have not been able to find one. The case of Mulready will, however, serve as an example of defects of colour-perception due to this cause. It is well known that the pictures which he painted in his later years are too blue, and in order to be seen to the best advantage they have to be looked at through a yellow glass. The cause of this defect was the yellow tint which the crystalline lenses acquire with age.

The degree of colour-defect due to absorption may be ascertained quantitatively. The result, however, will be only relative to that of the examiner. For instance, Mulready relatively to most persons saw too much yellow in nature, whilst the same persons taking Mulready as a standard saw too much blue. In order to ascertain quantitatively the degree of the defect we must first exclude colour-blindness due to defective psycho-physical perception, and colour-blindness due to a shortened spectrum, and then test the individual with an apparatus for mixing spectral colours in definite proportions. The appearance of definite mixtures should be noted. A certain amount

of blue being found to neutralize a definite amount of yellow for the examiner, it should be noted whether more, or less blue is required for the examinee, and the relative proportions of each colour. The yellow and blue must in every case correspond to definite points of the spectrum scale. The intensity of the colour may be regulated by increasing or diminishing the intensity of the source of light. In the same way the proportions of red and green necessary to make yellow, and the proportions of green and violet necessary to make blue should be ascertained. The proportions of the different complementaries necessary to make white should be recorded.

There is not much to be said about Class III., namely, colour-defects due to pathological conditions. These rarely exist apart from other diseases of the eye, and are fully considered in treatises on these diseases. The remainder of this chapter will be devoted to considering Classes II. and IV., namely, colour-blindness due to shortening of the spectrum, and colour-blindness due to defective psycho-physical perception.

Methods which are employed in order to ascertain the nature of the colour-perception of the colour-blind must be separated from, and considered entirely apart from those which are employed in order to determine whether colour-blindness be present or not for some definite practical object. The length of time which must be spent over one case, in order that it may be subsequently used as a basis for classification, is generally very great. The results obtained by the following methods agree in all particulars.

A. Information afforded by the Colour-blind themselves.—We may obtain very valuable information from the colour-blind, if their remarks be taken down without question. It is absolutely necessary that no leading ques-

tions be asked. A colour-blind person who talks about a greenish purple probably belongs to the four-unit class, whilst another who talked about a reddish green would probably belong to the three or two-unit class.

The following questions should be asked:—

1. How long have you found difficulty in distinguishing colours?

2. What colours do you confuse?

3. What effect has gaslight upon colours?

4. Does distance make any difference in the appearance of colours?

5. Are you fond of colours? What is your favourite colour?

6. Does the ordinary classification of colours appear to you correct?

7. Give examples of objects which appear of a decided colour.

8. What colours appear the most definite?

9. Have you tried to cultivate a knowledge of colours, and, if so, with what result?

10. Have you any relative who cannot distinguish colours?

He should then be asked to name a large number of coloured objects. This method of examination is very useful as a preliminary, because a colour-blind person will name colours in accordance with his psycho-physical perception of colour, and we shall thus obtain a very good idea of the class to which he belongs. Many writers on colour-blindness have stated that naming colours is a useless and misleading method of examination, because the colour-blind must use the conventional colour-names, and use them at random. But this argument is a fallacy, because the colour-blind do not name colours at random, but in accordance with their ideas of colour. I will make this clear with an

example. Let us compare the class of the seven-unit with that of the six-unit. The former class of persons see a definite colour at the point of junction of the blue and violet of the six-unit. It is evident, therefore, that the seven-unit are able to classify colours corresponding to this portion of the spectrum, and would give a definite name to the class, whilst the six-unit are not able to make a correct classification, and call the colour either blue or violet. When a colour-blind person names a colour in strict accordance with his ideas on the subject, he tells us which colour the object under observation resembles *to him*. Naming colours is a method of roughly classifying them, and the errors may reveal the nature of the defect. For instance, a two-unit would never call yellow, blue; or blue, yellow: whilst he would call red, green; and green, red. A three-unit never calls red, green; or green, violet: but calls violet, blue; and orange, red. The subject of colour-names will be considered more fully in a later chapter.

Anything abnormal or uncommon about the eyes should be noted. In many colour-blind persons a curious appearance of the eyes may be observed. In most persons the lower lid covers the edge of the iris; but in many colour-blind persons the lower lid does not extend as far upwards as the iris. This gives a very odd and unnatural appearance to the eyes. I mention this because it has enabled me to detect several colour-blind persons.

Wilson speaks of a peculiarity of expression in the eyes of certain of the colour-blind. He says—

"One has an absent, anxious glance, with something of the expression which amaurosis gives, only the pupil is small. One has a startled, restless look. The other two have an eager, prying, aimless air. The character common to them all, and to the other cases I have seen, is this aimlessness of look."

It is very difficult to obtain a definite idea of the expression described by Wilson. Many normal-sighted persons have an anxious glance when being examined, and I think that this depends upon the temperament of the individual.

The reader can obtain an idea of the expression which I have described above, by looking at a spot on a mirror on a level with the eyes, and then, keeping the eyes fixed upon this spot, bend the head forwards until the sclerotic is visible below the iris.

B. Examination with the Spectrum.—From a scientific point of view, this is the most important method of examination, as it gives the key to all the mistakes made. The eye-piece of the spectroscope which is used must be provided with shutters, so that any portion of the spectrum may be separated from the adjacent colours.

Both the solar and gas spectra may be used. The difficulty with the latter spectrum is that it contains a paucity of blue rays, and on this account presents a sort of natural blue-green junction.

The spectroscope should be arranged so that yellow occupies the middle of the field, with green on one side, and orange and red on the other. The examinee should then be asked to name the colour of the field. I have invariably found the two-unit colour-blind reply, "Yellow;" the three-unit, "Red, gradually passing into green;" the four-unit, "Red, yellow, and green," and the normal-sighted have named all four colours correctly. It is necessary to commence the examination in this way for two reasons; the first, is that it gives us at once a very fair idea of the colour-perception of the individual; the second, is that it prevents the colour-blind from *making* colours, and so saves time. If we commence—as I did at first—by asking the colour-blind to mark off the red, then the next colour,

and so on, if he be educated, with a knowledge of colours and of the spectrum, he will try to find some guiding point, and then calculate the position of the colours. I have had a two-unit colour-blind mark out all the colours (not correctly) in both the solar and gas spectra, when I examined him commencing with the red. Subsequently I examined him again, commencing in the above way, when he remarked that the field was all yellow, showing at once that he belonged to the class of the two-unit colour-blind. The half of the red, orange, yellow, and about half of the green present a field of almost equal luminosity. The colour-blind person does not know what he is going to see, and therefore answers *as he sees*, whilst any normal-sighted person at once sees, and names the colours shown. The next process is to ascertain the points of junction of the different units. This is done by moving the spectrum until the pointer of the eye-piece is situated at the junction between the two colours. The shutters of the eye-piece are useful here, so that all the colours with the exception of that directly under observation may be excluded. There will then be usually no difficulty in ascertaining the correct junction.

The bands of colour having been carefully marked out, the examinee should be tested with regard to the length of his spectrum for bright light, whether normal in length, or shortened at either the red or the violet end. This may be done with the aid of the shutters so as to insure perfect accuracy. Half of the field should be black, and the other half should contain the termination of the spectrum, either the red or the violet end. The examinee should then be requested to push in the shutter until all colour just, and only just, disappears from view. He should then be tested with a spectrum of diminished intensity, obtained by nearly closing the slit of the

spectroscope. If the spectrum be shortened for coloured light of diminished intensity, the examinee should be tested with coloured light more towards the centre of the spectrum. Thus, if the violet end of the spectrum of diminished intensity be shortened, one shutter should be placed over the shortened portion, and the remainder of the violet allowed to occupy the field. The examiner should then reduce the intensity of this portion by closing the slit until the violet is only just visible to him, and then test the examinee with it. I have always found that the colour-blind are able to see the colour. This experiment gives us two important facts—namely, that there is really shortening of the spectrum of diminished intensity, and that it is not the diminution of the intensity only which causes the non-recognition of the light. The points of greatest luminosity in the spectrum should also be ascertained.

I consider the above the most accurate method of examining the colour-perception of a colour-blind person. Small personal details will not affect the result of the examination. For instance, if we are examining two colour-blind persons whose psycho-physical perception is similar, but one has much yellower lenses than the other, the result will not be altered, because the absorption of a certain number of blue rays will not prevent those blue rays which are transmitted from being perceived as blue, and will not affect other portions of the spectrum. The object of the examination is to find out the appearance which the spectrum has to different classes of persons. The examinee is shown a portion of the spectrum which has a certain definite appearance to the normal-sighted. Take, for instance, the examination of a three-unit. A person belonging to this class, on being shown the red, orange, yellow, and green, of the spectrum, says that he

sees red, greenish red, reddish green, and green. Now, to a normal-sighted person, yellow appears as a definite colour, not as reddish green, in fact it is impossible for a normal-sighted person to form any idea of a reddish green. There are many other methods of examining the colour-blind with the spectrum, a favourite method being with mixtures of spectral colours. But there are obvious disadvantages in examining in this way, thus if a three-unit had got into the habit of calling a greenish red, yellow, he would equally call a mixture of red and green, yellow, and this mixture appears yellow to the normal-sighted.

If the wave theory of light be accepted, then the first step towards a proper appreciation of the physiological phenomena of colour must be made with reference to the effect upon the mind of different portions of the spectrum. It is obvious that we cannot properly comprehend the influence of mixed lights upon the mind until we understand the perception of the simplest and purest kinds of light. A spectrum has a definite appearance to all persons, but what we wish to find out is, does the impression which one person receives from the spectrum correspond with that received by another person? that is, are the impressions identical? A normal-sighted person sees six definite colours in the spectrum—red, orange, yellow, green, blue, and violet. The names applied to these colours are of little importance. It is sufficient to find out that the junctions of the colours correspond. But when one person says that the junction of his blue and green is at a point nearly in the centre of the blue of the normal-sighted, it is obvious that the spectrum presents a different appearance to him from that which it presents to the normal-sighted. Again, when a person says that in his opinion there is no definite colour at the point

occupied by the yellow of the normal-sighted, but merely a transitional colour which is accurately named when called red-green, it is evident that he sees the spectrum differently from the normal-sighted. This method is one of a comparison of pure colours under the most favourable circumstances, and the accuracy of the results obtained is borne out by other methods of examination. Supposing, for instance, that a four-unit colour-blind is shown the blue and the violet of the spectrum, he says that there is only one colour in the field, namely violet. The fact which we have obtained under these circumstances is that he does not see the *difference* between blue and violet, which is so evident to the normal-sighted, but receives a single impression from the whole of the waves of light included in the portion of spectrum occupied by the external two-thirds of the blue and the violet of the normal-sighted. In no other way can we obtain such definite facts as to the appearance of the spectrum to the colour-blind, and we must remember that the appearance of the spectrum must be the basis of all ideas of colour.

C. A General Classification of Colours.—This method of examination affords abundant confirmatory evidence of the truth of the spectroscopic examination. The colour-blind will classify in accordance with their psycho-physical perception. Coloured objects of different materials should be used, so as to force the examinee to use his colour-perception in classifying them. I use coloured wools, silks, enamels, cards, glass, solutions, velveteens, porcelain discs, and coloured papers. This is necessary, because an ordinary redgreen-blind will not put a green and a yellow wool together, because the latter appears so much brighter; but he will put a green silk skein with the yellow wool skein, and he will put red, green, and yellow glass with both.

Very accurate results may be obtained in this way, as the majority of the colours of coloured objects correspond to similar points of the spectrum. Many persons are able to find out whether a colour is a green or a blue by comparing it with a green or a blue respectively. There is no reason why they should not do this as long as they do not obtain any aid from the relative luminosity of the colours. For this reason a large number—about 150—of coloured wools should be given to the colour-blind to classify. This having been done, a few only of different-coloured materials should be given at a time, so that they may be matched with the wools, and not among themselves. The colours used should represent the whole series of colours, red, orange, yellow, yellow-green, green, blue-green, blue, violet, purple, crimson, and numerous shades of brown and gray.

I have each colour in the series which I have used numbered (irregularly and with no system), so that I can keep a record of the mistakes made, and the exact colour of the objects mistaken.

In addition to the ordinary coloured objects, I use several pieces of changeable silk ribbon. Three of these pieces I have included in my Pocket Test, Nos. 119, 120, and 121. These colours show that colours apparently identical to the normal eye, have often a very different composition which the change from natural to artificial light may bring out in a marked manner.

Classifications should be obtained by gaslight as well as by daylight.

This method of examination gives us definite facts which are useful in classifying the colour-blind. Many physicists say that these facts are useless because the colours are not pure, but, if two pieces of coloured wool, one red and one green, give rise to distinct sensations of colour

with one person, and to similar sensations with another person, we have obtained definite facts. On referring to the chapter on the classification of the colour-blind, it will be seen that the classification of coloured materials is in accordance with the spectroscopic examination. As I have stated in the first part of this chapter, the alteration in the appearance of a pigmentary colour by absorption of some of the reflected rays by the media of the eye, has been very much exaggerated. If we find that a person is able to classify three hundred pieces of coloured material as the normal-sighted would classify them, we may conclude that this person is normal-sighted. I have found that an examination with coloured wools gives us very accurate information as to the colour-perception of an individual. The mistakes made are in accordance with the psycho-physical colour-perception of the person examined.

D. Test by Painting.—This method shows the colour-perception of the individual examined very accurately A large number of colours should be arranged on plates, both primary and mixed, so that the examinee may have as little mixing as possible to do himself. The theory of psycho-physical perception should be carefully borne in mind in arranging the colours, and then the examiner may insure mistakes being made. Thus, even with the five-unit reddish orange is a decided red, so that if colours corresponding to points well within the limits of the enlarged unit be used, the colour-blind are certain to make mistakes. In testing the two-unit, for instance, light red, olive-green, and bright yellowish green should be put on the plates as prominent colours. The colour-blind should be told to paint the whole of one colour before proceeding with the next. As the colour-blind only see perfectly definite colours at the centre-points of their approximate

units, they will, when representing a colour, only be satisfied when they use a colour corresponding to this centre-point. The four-unit have the centre of their violet-unit corresponding to the blue-violet of the normal-sighted, and they will always represent blue by this colour if they have the opportunity, in preference to Prussian Blue, which would be used by the normal-sighted. The ordinary two-unit colour-blind rarely uses Crimson Lake to paint the reds, as a normal-sighted person would, but uses light red, or olive-green.

I use a variety of the small German pictures for little artists. These pictures consist of a copy which is very fairly coloured, and a pencilled outline, so that the student has only to fill in the colour. I have a series, consisting of thirty-eight paintings and five colour-matches executed by persons more or less colour-blind, and under various conditions of light. The mistakes made show the colour-perception of the artist very accurately.

Plates II. and III. are constructed from the pictures painted by colour-blind persons.

Fig. 16*a* represents Fig. 16 as painted by a four-unit colour-blind person. He has represented blue by green, red by crimson, and pink by yellow.

Figs. 18*a* and 19*a* represent Figs. 18 and 19 as painted by persons belonging to the class of the three-unit. Figs. 18*b* and 19*b* represent Figs. 18 and 19 as painted by persons belonging to the class of the two-unit. It will be noticed that the mistakes made in each case are different and characteristic. In Fig. 18*a* yellow has been represented by red, blue by violet, and brown by red. The green is also of a different hue to that of the copy. In Fig. 19*a* the reddish portion has been correctly painted, but brown has been represented by green. The green is also not so yellow as that of the copy.

Fig. 16.

Fig. 16a.
Tetrachromic.

Fig. 17.

Fig. 17a.
Dichromic.

Fig. 18.

Fig. 18a.
Trichromic.

Fig. 18b.
Dichromic.

Fig. 19.

Fig. 19a.
Trichromic.

Fig. 19b.
Dichromic.

Fig. 20.

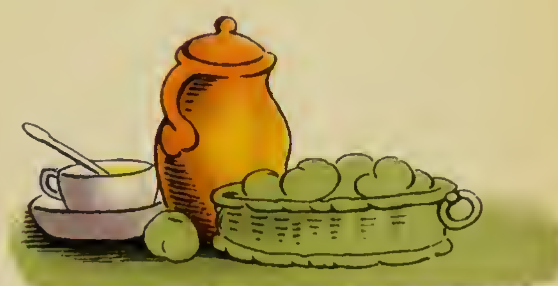

Fig. 20a.
Dichromic.

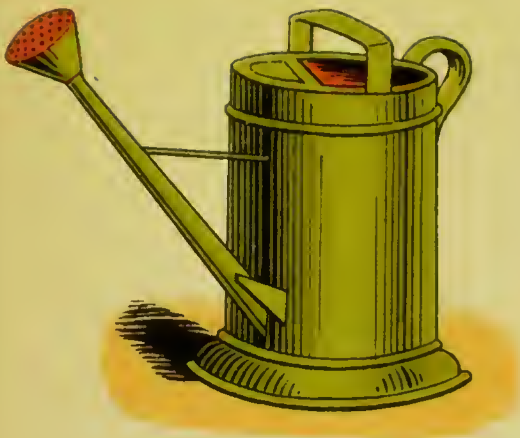

Fig. 21.

Fig. 21a.
Dichromic.

Fig. 22.

Fig. 22a.
Dichromic.

Figs. 17*a*, 18*b*, 19*b*, 20*a*, 21*a*, and 22*a* are from paintings by persons belonging to the class of the two-unit. Figs. 17*a*, 18*b*, and 22*a* are by persons with spectra of normal length. The two-unit who painted Fig. 20*a* had a spectrum shortened at both ends. The person who painted Fig. 19*b* had a spectrum shortened at both ends, and a neutral band in the blue-green. The two-unit who painted Fig. 21*a* had a spectrum shortened at both ends, and a very large neutral band in the blue-green, green, and blue; hence both red and green have been represented by gray. The person who painted Fig. 16*a* had a spectrum shortened at the red end, whilst the three-units who painted Figs. 18*a* and 19*a* had spectra shortened at both ends.

Figs. 18*a*, 18*b*, and 20*a* were painted by daylight. Figs. 16*a*, 17*a*, 19*a*, 19*b*, 21*a*, and 22*a* were painted by gaslight. Many authors state that colour-blind persons can distinguish red from green by gaslight. Fig. 22*a* shows that this is not the case.

E. Examination with Colours at a Distance.—The examinee should be examined in order to find out whether distance makes any difference in the appearance of colours. The examination with the Lantern Test is a practical examination, and distance is imitated. The details of this examination are described fully in a succeeding chapter.

F. Examination for Twin Colours.—The candidate should be asked to pick out from the bundle of wools any pairs which appear absolutely identical in colour and shade. He should be allowed to compare them very carefully, so as to make sure that he has selected pairs which appear exactly alike to him.

G. Examination as to the Perception of Shade.—The examinee should be asked to match wools of different

colours, only paying attention to the shade. The point of non-recognition of the colour and light of the spectral colours when reduced in luminosity by the method described on p. 113, should be noted.

H. Test as to the Perception of Complementary Colours.—The colour-blind person should then be tested as to his power of seeing complementary colours. A method which I have found very effectual for this purpose, is to let the examinee look through a piece of coloured glass at a gas flame for about forty seconds, and then look at a sheet of white paper. A great advantage of this method is that the composition of the colour of the glass used in the experiment can be accurately determined by the spectroscope.

The examinee may also be tested with the after-images of coloured cards, and shadows coloured by contrast. The latter may be obtained by interposing a pencil between a piece of coloured glass and a sheet of white paper, the glass being between the light and the paper.

I. The Colour-top.—This is an instrument which has been used very extensively by physicists in order to form colour equations. The colour-top was first described by Newton, but does not appear to have been used by him. Maxwell's name is associated with this top. He says—

"The coloured paper is cut into the form of discs, each with a small hole in the centre and divided along a radius, so as to admit of several of them being placed on the same axis, so that part of each is exposed. By slipping one disc over another, we can expose any given portion of each colour. These discs are placed on a little top or teetotum, consisting of a flat disc of tin-plate and a vertical disc of ivory. This axis passes through the discs, and the quantity of each colour exposed is measured by a graduation on the rim of the disc, which is divided into a hundred parts.

"By spinning the top, each colour is presented to the eye for a time proportional to the angle of the sector exposed; and I have found by independent experiments, that the colour produced by fast spinning is identical with that produced by causing the light of the different colours to fall on the retina at once."

In order to test the results of experiments made in the above way, I constructed an apparatus which is only a modification of the above-mentioned colour-top. The apparatus consists of six wooden discs, each being three inches in diameter, and half an inch thick. These are arranged on an axle connected with a series of wheels, so that the discs can be rotated, by turning a handle, with considerable velocity. Attached to the circumference of each disc are two lips, so that pieces of coloured cardboard may be put round the circumference of each wheel. It will be seen that any number of colours may be combined on one wheel, and compared with colours on other wheels. This method of experimenting allows colours under exactly the same conditions to be compared, which is not the case when the colours are placed horizontally and one colour occupies the centre of the disc whilst the other is more towards the circumference.

The most obvious fallacy of this method of experimenting is, that the colours mixed are not pure; thus, if the colours of the tapes be yellow and blue, we are not mixing pure yellow and blue light, but all the rays of light which go to make up the yellow on the one hand, with all the rays of light which go to make up the blue on the other. By the polariscope we can split white light into two portions, one yellow and one blue, and these, on being mixed, will again combine into white light. From this it will be seen that, in the mixture of yellow and blue light which reaches the eye from the coloured

tapes, the whole of the rays of the spectrum may be represented. Maxwell says that similar results are obtained with this method of experimenting to those obtained with pure spectral colours. If this be the case, it will strongly support the following proposition: *If a mixture of two pure spectral colours gives rise to a certain colour, then a mixture of rays giving rise to the sensation of one of these colours being mixed with a series of rays giving rise to the sensation of the other will produce a similar colour.* It is necessary that the above proposition should be proved to be true before results obtained by colour-mixing in this way have any scientific value.

J. Other Methods.—In addition to the methods mentioned above, I have tested colour-blind persons with regard to their power of seeing after-images and colour-changes due to contrast; the appearance of objects through coloured glass; their perception of colours of a very low degree of saturation; the perception of slight modifications of pigmentary colours; their memory for colours; and with coloured objects, which markedly change by artificial light.

With regard to other tests for colour-blindness. My Pocket Test will be found useful, but could not be used for testing sailors or engine-drivers, because the candidate could buy one and study it with the aid of a normal-sighted person.

The test is based on the theory of psycho-physical perception, and I have found it answer admirably. Several examinations with this test are recorded in Chapter XIII. It consists of 112 single threads of wool, thirteen pieces of twisted silk, nine small pieces of cardboard, three pieces of changeable silk ribbon, and one piece of green velvet. These (with the exception of the end threads of each row) are numbered consecutively.

The end threads of the first four rows are numbered from I. to VIII. in Roman numerals, and form the tests; they are Orange, Violet, Red, Blue-green, Rose, Pure Green, Yellow-green, and Electric Blue. The changeable silks change very considerably when taken from daylight to gaslight, the most marked change being from bright green to purple. The series of colours, I have selected and arranged so as to confuse the colour-blind and force them to be guided by their colour-perception, whilst the quantity of colour is amply sufficient for the normal-sighted to pick out the colours with the greatest ease. The two most important test colours are the Orange and Violet, Nos. I. and II. The person examined should be asked to pick out the shades of colour similar to No. I. (orange). If he do this correctly, he probably possesses normal colour-perception, and may be passed. If, however, he match the test with reds or pinks, he is more or less colour-blind, at best belonging to the five-unit class. If, in addition, he match the Violet test, No. II., with blue, he at best belongs to the four-unit class. The three-unit colour-blind, in addition, matches the Blue-green test, No. III., with green. Other mistakes will be made; thus the two-unit will match the Orange test, No. I., with yellow-green and yellow-brown, but the above are the diagnostic signs for each class. Most of the varieties of the colour-blind will be readily detected in this way. The other four tests are confirmatory and elucidatory, modifications occurring when there is shortening of the spectrum or a neutral band is present.

The special advantages of this test are:—

1. The colour-blind can be ranged definitely in their proper classes.

2. Central Scotoma can be detected with its aid.

3. The series of colours are arranged so as to confuse

the colour-blind, whilst the normal-sighted easily match the test colours.

4. On account of the introduction of different materials, the relative luminosity of colours does not serve as a guide to the colour-blind.

5. Portability.

6. The wools, etc., are kept clean.

7. An important colour is not likely to be lost.

I have had a special spectroscope constructed for estimating colour-perception. In the focus of the instrument are two movable shutters, either of which is capable of moving across the spectrum. By means of the two shutters any given portion of the spectrum can be isolated. Each shutter is controlled by a drum graduated in wave-lengths, so that the position of the edges of the shutters can be known. The accuracy of the graduation is to 5 Ångstrom units.

We can ascertain with this instrument the exact size of portions of the spectrum which appear monochromatic, and their varying size with different persons. We can also determine the limits of visibility on both sides of the spectrum, the exact size and position of the neutral band in different dichromics, and the position of the most luminous portion of the spectrum.

CHAPTER XII.

COLOUR-BLINDNESS DUE TO DIMINUTION IN THE VISUAL RANGE.

THERE is another variety of colour defect which is quite separate from diminution in the number of the psycho-physical units, and that is due to shortening of the spectrum. The spectrum may be shortened for bright light, or for light of diminished intensity. The amount of shortening is very variable, and many cases of two-unit colour-blindness are met with in which there is no shortening. When a spectrum of diminished intensity is shortened, it will be found that the diminution of intensity will not wholly account for the defect. For instance, let us take a colour-blind person with a spectrum shortened at the violet end for light of low intensity. If the shortened portion be cut off with a shutter, and a portion of violet internal to this be taken, it will be found that he will recognize this, even if its intensity be reduced to a point at which it is only just perceptible to the normal-sighted, and considerably below the intensity of the defective portion at the point of non-recognition. I have not been able to find a colour-blind person who failed to recognize the green as some colour or light, even when reduced to the lowest degree of intensity visible to the normal-sighted. This shortening of the spectrum, either at the red or the

violet end, appears to be very common, and is a frequent accompaniment of true colour-blindness. This condition is probably due to some defect in the retina, whereby it is unable to respond to rays of light of very low or very high refrangibility, or in some cases to both, the bright gas spectrum being shortened at both ends.

The shortened portion is indistinguishable from black; that is to say, not only is the red or violet not perceived as a colour, but it is not perceived at all. The importance of ascertaining whether there is shortening of the red end of the spectrum will be seen, when it is borne in mind that the red rays, especially those at the extreme left of the spectrum, are the most penetrating and visible when the others are obscured. There must be few who have not noticed the red appearance of the sun on a foggy day. The power these red rays possess of passing through semi-opaque bodies may be demonstrated by taking about eight pieces of neutral smoked glass, and looking at the gas flame through them. On looking through a single piece of glass the gas flame appears dimmed, and not quite so yellow. On looking through three pieces, the flame is distinctly reddish, and the purity of the red is only increased by adding another piece. This red is only slightly dimmed by using all eight pieces. An examination with the spectroscope in the same manner, shows that the colour is due to a band of red on the extreme left of the spectrum. The practical outcome of this is that a colour-blind person whose spectrum is shortened is not able to see a red light under conditions in which it is very obvious to the normal-sighted.

It now remains to consider the influence of a shortened spectrum upon colour-vision. The first evident fact is, that bodies reflecting only light, the rays of which occupy the shortened portion of the spectrum, appear black.

Nearly all colours are compound; that is to say, the coloured body reflects other rays than those of the colour seen. Thus a blue-green glass may transmit the green, blue, and violet rays of the spectrum. The colour of a body is usually the centre unit of all the rays reflected or transmitted. Let us suppose that we have a substance reflecting the green, blue, and three-quarters of the violet, the colour of the body being green. Then, if we had another substance which reflected the whole of the violet, it would appear blue. But with a person who could not perceive the terminal fourth of the violet, the colour would look exactly the same as the green one, and, as he could not distinguish between the two, he would be in continual difficulty with blues and greens.

All colours reflecting rays occupying the shortened portion, appear darker than they do to the normal-sighted, and are always matched with darker colours belonging to a point more internal. Thus a two-unit colour-blind with a shortened red end of the spectrum matches a red with a darker green.

It will be noticed that a shortened spectrum, especially if one end only be affected, may interfere very little with the general appreciation of shade.

If for instance, we take a case in which the red end of the spectrum is shortened, so that only three-quarters of the red of the normal-sighted is seen; then all bodies which equally reflect or transmit these rays can be correctly compared, because a similar portion of light has been removed from each.

It is only when one colour reflects or transmits the rays occupying the shortened portion, and the other does not, that there is any definite interference with the appreciation of shade. Again, if neither colour reflects or transmits rays occupying the shortened portion of the

spectrum, there will obviously be no interference with the appreciation of shade.

A very common mistake due to shortening of the red end of the spectrum is the confusion of pink and blue. If a person with considerable shortening of the red end of the spectrum is shown a pink which is made up of a mixture of red and violet, the red consisting of rays occupying the extreme left of the spectrum, only the violet is visible to him, and so the pink appears as violet without a trace of red. This pink is therefore matched with a violet or blue very much darker than itself.

Mistakes which are due to shortening of the spectrum may be remedied if we subtract the rays occupying the shortened portion from the colour of confusion.

For instance, if we take a blue and a pink which have been put together as identical by a person with a shortened red end of the spectrum, and look at them through a glass which is opaque to the red but transparent to the remaining rays of the spectrum, both will appear alike in hue and shade.

A person with considerable shortening of the red end of the spectrum will look at a red light (which is so dazzlingly bright to a normal-sighted person as to make his eyes ache after looking at it closely for a few seconds), at a distance of a few inches, and remark that there is nothing visible, and that the whole is absolutely black. It is obvious that the light must only consist of rays occupying the shortened portion of the spectrum.

CHAPTER XIII.

THE CLASSIFICATION OF THE COLOUR-BLIND.

In the preceding chapters I have discussed the causes of colour-blindness. The chief causes are—

1. Diminution in the number of psycho-physical colour units.

2. Shortening of one or both ends of the spectrum.

An examination with the spectrum gives a key to the colour-vision of any person. We can record the number of units which a person sees in the spectrum, and the degree of shortening in each case. It will then be found that persons will make mistakes in accordance with the examination with the spectrum. In the first class we may include those persons who, whilst belonging to the class of the six-unit, have a spectrum which is shortened at one or both ends. The remainder of the colour-blind may be classified according to their psycho-physical colour-perception. Then, if the normal-sighted be designated hexachromic, the five-unit may be called pentachromic, the four-unit tetrachromic, the three-unit trichromic, the two-unit dichromic, and the one-unit totally colour-blind. In addition, the degree of shortening of the spectrum should be recorded, if present. In the case of the two-unit, the presence or absence of a neutral band should be recorded. When present, its relative size should be given. It is obvious that a classification which is based upon

what the colour-blind actually see must present many advantages over one which is based upon theoretical deductions. Though the facts on which these classifications are based were obtained in the first place by theory, this has no effect upon the circumstance that they are facts with which any future theory must conform. In this classification I have therefore given typical cases, and the methods which I used to ascertain the colour-perception of the individuals examined. The coloured plate at the commencement of this book is constructed from actual cases with the single exception of Fig. 10. This figure represents a case of total colour-blindness, a condition which has not at present come under my observation. Fig. 2 in the frontispiece represents the spectrum as seen by most persons. This may therefore be called the normal, and all other cases compared with it. This is done in the plate by dotted lines, which pass through the points of junction of the adjacent units in the psycho-physical spectrum of the six-unit. This shows the corresponding points in the other psycho-physical spectra.

From a consideration of the theory of psycho-physical perception, it will be seen that the cases included in each class are not necessarily exactly alike, because the classification is made in accordance with the number of *approximate* psycho-physical units seen. Cases to be exactly alike would have to correspond in the number of absolute psycho-physical units. A classification in accordance with the number of approximate psycho-physical units seen is sufficient for all practical purposes, because the mistakes made by those included in one class only vary in degree. Take, for instance, the class of the three-unit: we may have three-units bordering on the class of the four-unit, or bordering on the class of the two-

unit; but in neither case will the mistakes made incline either to the four-unit on the one hand, or the two-unit on the other. The mistakes made will be those of a typical three-unit; but they will be more prominent in the case of the person bordering on the two-unit than in that of the person just below the four-unit. The reason of this is evident on considering the theory of psycho-physical perception. A person belonging to the class of the four-unit is able to see yellow as a definite colour, but a three-unit only sees yellow as reddish green; therefore, directly perception is reduced to a point below that necessary for perceiving yellow as a distinct colour, three-unit mistakes will be made. The same applies to those cases which border on the class of the two-unit. As long as the colour-perception of an individual is sufficient to enable him to see three definite colours in the spectrum, he will not make the mistakes of the two-unit class, as he is able to see red, green, and violet as definite colours.

Six-unit with Shortened Spectrum.

The following case illustrates the condition of a six-unit with a shortened spectrum.

A. A.—This gentleman told me that there was something wrong with his perception of colour, as he confused colours in some materials and not in others. His confusing colours was rather the exception than the rule, and he found that he was much more colour-blind some days than others. He chiefly found difficulty with colours by gaslight.

I. Examination with Solar Spectrum.—He marked out the junction of the colours correctly enough, and the commencement of his red agreed with mine. His violet was shortened by about one-sixth for bright light.

II. Examination with Pocket Colour-test.

1. Daylight.

I. *Yellowish red.* 67, 76, 111. Orange.
II. *Mauve.* 9, 33, 65, 68, 77, 103, 93, 129. Violet.
III. *Brick-red.* 36, 95, 116. Red.
IV. *Blue-green.* 80, 11, 51, 122. Green.
V. *Lake.* 52, 21, 41, 31, 79, 130, 127. Rose.
VI. *Green.* 100. Green.
VII. *Yellow-green.* None similar.
VIII. *Blue.* 3, 45, 40, 56. Blue.

2. Gaslight.

I. 79, 7, 12, 76, 116, III. Orange, red, and crimson.
II. 82, 88, 93, 90. Violet and brown.
III. *Reddish brown.* 7, 12, V. (This, he said, had a little more brown in it.) 62, 67, 76, 79, 104, 111, 116, 123. Red, rose, and orange.
IV. *Green or Blue, perhaps Greenish blue.* 2, 15, 45, 51, 56, 75, 78, 84, 92, 100. Blue-green, green, and blue.
He was very doubtful what to call IV. On looking at it again, he said that he thought there was more green than blue in the colour.
V. *Yellow-brown, Burnt Sienna, or Burnt Umber.* 31, 38, 62, 76, 104, 99, 111, 123. Rose, brown, red, and orange.
VI. *Lavender.* 40, 32, 11, 56, 81, 86. Green, blue, and blue-green.
VII. *Pearl-gray.* 18, 23, 43, 50, 101, 125, 115. Light rose, fawn, gray, and green.
VIII. *Deep blue.* 3, 20, 24, 49, 55, 66, 72, 108. Blue, green, and blue-green.

In this and other records of examinations with my Pocket Colour-test, the number of the test colour is put first: I. being Orange, II. Violet, III. Red, IV. Blue-green, V. Rose, VI. Green, VII. Yellow-green, and VIII. Electric Blue. Following this is the name given to the colour by the examinee. When no name appears it shows that the examinee was not able to name the colour. Then come the numbers of the confusion colours of the test, selected by the examinee. These are followed by the real names of the confusion colours selected.

I tested him by gaslight with a book of coloured pictures. He could not distinguish pink from blue in some cases. He called very dark green, blue. By gaslight he never seemed very certain of any colour.

In this case it will be noticed that the selection of colours by daylight is very similar to that made by the normal-sighted. The mistakes made by gaslight are quite different to anything that I had previously encountered. They do not correspond to any recorded case. I was at first very much puzzled to account for the mistakes, as the examination with the Pocket Test was made some weeks before the spectral examination. The shortening of the violet end of the spectrum gives a key to the mistakes made. Let the reader take a piece of yellow glass, such as that in the Classification Test, which is opaque to the violet and blue rays whilst it is transparent to the green, yellow, orange, and red rays. On viewing the colours in the Pocket Test through this glass the selection made above is explained. A normal-sighted person, having to make a classification of the colours through the yellow glass, would make a very similar selection. The reason why the mistakes made by gaslight are so very much greater than those made by daylight is that there is a paucity of blue rays in gaslight. A shortening of the violet end of the spectrum, which would have very little effect by daylight, would have a very considerable effect by gaslight.

The paucity of the blue rays, and the shortening taken together, would make blue and violet almost invisible by gaslight; whilst the preponderance of blue rays in daylight would prevent the shortening of the spectrum from having much effect.

When the only colour defect is shortening of the red

end of the spectrum, red, especially when dim, is not easily seen at a distance, and bacilli stained red may under a microscope appear black. The following case recorded in a letter in the *Times*, January 25, 1890, seems to be an example of this class. **G. P.** says—

"My late wife was partially colour-blind. She could not see at a distance the colour of a red railway signal. She could not see the red coat of a soldier at two hundred yards distance; a bright orange-colour display of the aurora borealis was to her white. Yet when the objects were near she could distinguish colours perfectly. The red geraniums near my window she could see as well as I could; but those a hundred yards off were lost in the green. She could choose and compare coloured silks or worsted, and could paint well, and was a remarkably good colourist."

The details of this case are not sufficiently clear to enable me to say for certainty that the woman mentioned above had normal psycho-physical colour-perception, the only defect being a shortened red end of the spectrum. Every fact given, however, points to this conclusion. Red, at a distance, is seen almost entirely by the rays at the extreme left of the spectrum, and, if the spectrum were shortened, these rays would not be perceived.

Five-unit.

This is the first degree of diminished colour-perception. Figure 3 of the frontispiece represents the spectrum as marked out by this class of the colour-blind. Colour, as a quality, is lessened to persons of this class. If asked to match a colour, they find difficulty in doing so, and have not a very good memory for colours. When examined with the spectrum, they are found to be

deficient in the orange band of the normal-sighted. If the examinee be acquainted with the colours of the spectrum, he may try to mark out an orange band, but he generally fails, and commences the yellow at the point of termination of his red band. The yellow does not occupy exactly the same position as that of the normal-sighted, the true yellow being slightly encroached upon by the green. The blue band is also less distinct, being encroached upon by the violet and the green.

This examination gives a key to the mistakes made by this class of the colour-blind. They always find difficulty with orange, rarely using the word, and regarding it as a superfluous term. By artificial light they confuse orange with reds, pinks, and browns. They do not see as much difference between the modified units and the units themselves as the normal-sighted do. Thus they are rarely able to say, without comparison, whether a certain green is a pure green, or has a shade of blue in it, to use a common expression. In the same way, they confuse crimson and scarlet, deep purple-violet and violet.

When examined with my Pocket Colour-test, by daylight, they put 7, 12, III., 116, and 111 with I., in preference to the shades of orange. No. 76 is generally chosen, but 99 and 109 are rarely included, being classed with yellows. III. and 116 are fairly pure reds. 111 is an orange-brown. 7 and 12 are not pure reds, but reflect a considerable amount of violet light, they are therefore very unlike I. By gaslight, 79 and 107 (rose-colour) are often put with I.

Four-unit.

Figure 4 of the frontispiece represents the spectrum as marked out by this class of the colour-blind. Persons belonging to this class can only see four colours in the

spectrum. These four psycho-physical units are red, yellow, green, and violet. The red band has increased in size, and meets the green at about the centre of the yellow, which is recognized as a colour at the point of junction. The blue band has disappeared, the green and violet bands meet at a point which corresponds fairly accurately with the junction of the middle with the inner third of the blue of the normal-sighted. Two-thirds, therefore, of the blue are included with the violet, one-third with the green.

It will be noticed that in this class the green band is broader than it is in any other. Marking off the green from the blue of the spectrum gives them considerable trouble, and when they have accomplished this, they are rarely satisfied with the division. The reason of this is obvious. When speaking of the five-unit, I said that their blue-green junction was in the blue of the normal-sighted. In the four-unit the junction is still more in the blue, but it is difficult to get the exact point marked out, because they have always been accustomed to hear a colour which appears green to them spoken of as blue. When they are set to classify a number of coloured objects they will put blues and blue-greens with the greens. Many blues will be put with the violets, and only one or two blues of the most marked character will be classed as blues.

They find more difficulty in distinguishing crimson from red than the five-unit, and put orange, red, and rose together as reds. Orange seems to give them especial difficulty.

The spectroscopic examination gives a key to the mistakes made. The chief mistake is that of putting blue with violet; thus, when examined with the Pocket Test, 24, 49, 55, and 106 (blues) are put with the Violet test No. II. These colours correspond to a point of the

spectrum external to the middle of the blue, and are therefore classed with violet. Colours which correspond to the inner third of the blue, as 40 and 45, are classed with green. The fact about their own colour-perception which they generally remark is, that they always find difficulty in telling blues from greens without comparison.

This class find great difficulty in telling the modified units from the units, classing crimson with red. Colour is to them a feeble quality of objects.

The following two cases belong to this class, and are important because in each case the person has known of his defect, and has done his utmost to remedy it. Both belong to the educated classes, and were well acquainted with colour-names. The first is a case of four-unit colour-blindness with shortening of the red end of the spectrum, the second with shortening of the violet end of the spectrum. The details of a case of four-unit colour-blindness with an unshortened spectrum are given at page 201.

B. A., Male, aged 17.—He was well acquainted with the fact that his sense of colour was defective. He had tried to overcome the defect without success. He was perfectly cognizant of the various colour-names. His chief difficulty consisted in distinguishing between blues and greens, and, by gaslight, between yellows and light grays.

I. Spectroscopic Examination (*Gas Spectrum*).—He saw four distinct colours in the spectrum—red, yellow, green, and purple. The spectrum was shortened at the red end for bright light, about one-tenth of the red of the normal-sighted not being recognized. The spectrum at the violet end was of the normal length. When the shortened portion of the spectrum was cut off, he was able to recognize red of very low intensity. He said the yellow

band was too small to be defined. He said that both the red and the green were brighter than the yellow. He put the junction of the green and the purple at about the junction of the middle with the inner third of the blue of the normal-sighted.

II. Classification of Colours.

I. DAYLIGHT.

Group 1. Vermilion, orange, bronze, brown, and pink.
2. Scarlet and crimson.
3. Rose, pink, and purple.
4. Blue, violet, and blue-green.
5. Green, and blue.
6. Black.
7. Brown and gray.
8. Slate and olive-green.
9. Yellow, light pink, and buff.
10. Purple.

II. GASLIGHT.

Group 1. *Reds.* Scarlet, crimson, rose, and orange.
2. *Yellows.* Yellow, orange, pink, light gray, and light brown.
3. *Greens.* Green and blue.
4. *Blues.* This group consisted of very deep blues, of which No. 24 of my Pocket Test is the representative colour. There were only two blue *wools* put in this group, and they were similar in colour to No. 24.
5. *Purples.* Purple and violet.
6. *Grays.* Gray, greenish gray, light brown, yellow, and light yellow-green.
7. *Browns.* Brown, buff, and gray. A dark olive-green velveteen was also put in this group.

White and black he classified correctly.

At the head of each group is the name he gave to it.

III. Examination with Pocket Test (*Daylight*).

I. *Orange.* 76, 99, 123, 58, 89, 104, 109. Orange and yellow-brown,
II. *Blue, Bluish green.* 9, 33, 40, 45, 49, 24, 16, 55, 66, 77, 93, 117. 129. Violet and blue.
III. *Orange-red.* 7, 12, 22, 28, 36, 83, 95, 116, 130. Red and crimson.
IV. *Green.* 2, 15, 20, 51, 53, 64, 72, 80, 92, 124, 118, 120, 112. Green.
V. *Rose.* 7, 12, 21, 18, 31, 79, 107, 127. Red and rose.

VI. *Grayish green.* 11, 51, 53, 75, 78, 84, 100, 101, 122. Green.
VII. *Yellow.* 5, 14, 48, 35, 58, 89, 99, 109, 113, 126, 128. Yellow-green, yellow-brown, yellow, and orange.
VIII. *Bluish green.* 3, 24, 33, 40, 45, 55, 66, 93, 108, 129. Blue, blue-green, and violet.

IV. Test by Painting (*Gaslight*).—He made a very fair copy of the picture I set him to paint, but with characteristic mistakes. He used no blue whatever, but painted the greens and blues uniformly with green. The green he used was in each case much bluer than that of the copy. All the reds he painted with crimson instead of scarlet. Where pink should have been used, he has employed uniformly an impure yellow.

V. Examination with Lantern Test.—Tested at a distance of fifteen feet with the standard red and green lights, he was able to recognize these under all conditions of obstruction. He also correctly named the neutral glasses when shown him alone.

VI. Test with Polariscope (*Daylight*).—Shown a field which consisted half of green and half of bluish green, he said the only difference between the two was that the pure green was lighter.

He made the following mistakes:—

Calling Violet	...	... Purple-green
Blue	...	... Green
Light red	...	... Yellow
Blue	...	... Bluish green
Violet	...	... Bluish green

VII. Test as to Perception of Complementary Colours (*Daylight*).—I tested him with the shadow thrown by a pencil on a piece of white paper, a coloured glass being interposed between the pencil and the light. In the first column is the name of the coloured glass, in the second that of the name he gave to the shadow.

Red glass	Green	Deep blue glass ...	Yellow
Deep yellow glass ...	Dark green	Light blue glass ...	Yellow
Grass-green glass ...	Reddish	Deep purple glass ...	Green
Blue-green grass ...	Orange	Light purple glass ...	Green

C. A., Male, Middle-aged.—He had always found difficulty with colours, though he had tried his utmost to educate himself with regard to them. His chief difficulty was with blues and greens. If one of these colours were shown him without any opportunity of comparison, he never felt certain which it was. Thus, two colours which looked to him similar, other persons declared to be different, and *vice versâ*. He thinks that the great trouble he has taken with colours has not been wasted, and that he has improved in his power of discriminating between them. He has hit upon the following novel way of being able to tell between a blue and a green. He has had the lower part of one of his windows covered with blue baize, the blue being of a typical character. Then, if he wishes to tell whether a colour is a blue or a green, he looks first at the colour and then at the blue baize. If the two are alike in colour he calls it a blue, if dissimilar, then he calls it a green.

I. Spectroscopic Examination.

I. *Solar Spectrum.*—He saw four definite colours in the spectrum—red, yellow, green, and purple. He marked out a yellow band that was too small. The green band also extended into the blue of the normal-sighted. The day was so dull that a bright spectrum could not be obtained.

II. *Gas Spectrum.*—The red end of the spectrum was of the normal length, but the violet end was considerably shortened. The violet was reduced to about four-fifths of the size of the normal-sighted. The red band extended to the yellow, which was very faint, and was encroached upon by the green. He said he could only see the yellow

as a colour occasionally; he called it a yellow line of confusion between the red and green. His blue-green junction was situated at about the point of union of the middle and inner thirds of the blue of the normal-sighted. He referred to the violet as purple—never as blue. The above refers to a bright spectrum. Tested with a spectrum of very low intensity, the commencement of his red was the same as mine. The shortened portion of the violet end of his spectrum being cut off, he recognized the other colours (green and red) when of very low intensity, and only just visible to me.

II. Classification of Colours. (*Daylight*).

Group 1. *Browns.* Brown wools only. Brown cards only. Brown, sage-green, olive-green, and deep purple velveteens. Brown, sage-green, olive-green, and deep purple enamels. He also put one orange-red enamel with this group. It was not a true red, as it reflected a quantity of green light.

2. Gray wools. Gray and slate velveteens. Gray enamels. Black and dark green cards.

3. *Reds.* Rose, scarlet, and deep red wools. Scarlet, heliotrope, crimson and deep purple velveteens. Scarlet, crimson, and brown enamels. Crimson and orange cards Red and purple glass. I told him to separate the scarlets from the crimsons, but he was not able to do so.

4. Orange, yellow, buff, light brown, and light gray wools. Yellow velveteen. Orange, yellow, light brown, light and olive green enamels. Yellow and buff cards. Yellow glass.

5. Light gray, white, and light brown wools. Gray velveteens, gray enamels. Light brown cards. White glass.

6. *Blues.* Blue and blue-green wools. Blue and light green velveteens. Blue, blue-green, and green enamels. Blue cards. Blue-green glass.

7. *Purples.* Violet, purple, and dark blue wools. Dark blue and purple velveteens. Dark blue enamels. Purple cards. Blue glass.

8. *Greens.* Green and blue wools. Green and blue velveteens. Green and blue enamels. Green cards and green glass.

9. *Blacks.* Black wool. Black, and a dark olive-green enamel.

10. *Pinks.* Red, rose, and pink wools. Pink velveteens. Pink and purple enamels. Pink cards. Purple glass.
11. Purple-gray and light pink wools. Gray enamels. Slate cards.

The above classification was made with a very large number of colours. I have given it more fully than the one in the preceding case, because of several important details. The predominant colour in each group is that named for the wools.

Examination with Pocket Test (*Daylight*).

I. 7, 12, 67, 68, 76, 104, 109, 123. Orange and red.
II. 3, 9, 24, 33, 68, 66, 93, 129. Violet, blue, and purple.
III. 7, 12, 28, 36, 83, 95, 130. Red and crimson.
IV. 2, 11, 45, 51, 53, 64, 78. 80, 94, 100, 101, 122, 124. Blue-green green, and blue.

I also tested him with several pieces of changeable silk, amongst which were 119, 120, and 121 of Pocket Test. By daylight he called 119 and 121 gray, and 120 green. By gaslight he called 119 and 120 purple, and 121 gray. Both sets of answers are fairly correct.

IV. Test by Painting.—He succeeded in making a very fair copy of the picture I set him to paint. The chief mistakes he made were that he represented yellow-green by blue-green, and, in one case, painted a part which should have been gray, brown.

V. Examination with Lantern Test.—I tested him at a distance of fifteen feet, to see whether he could recognize the green and red lights under varying degrees of obstruction. This he did in all cases, correctly distinguishing the red, green, and neutral glasses. The only mistake he made was that of calling the standard green, blue.

The above two cases, taken with the record of the left eye, in the case of asymmetrical colour-perception

described on page 201, *et seq.*, are sufficient to exemplify the class of the four-unit colour-blind.

The numerous other cases I have examined belonging to this class are similar. The uneducated make similar mistakes to the educated; but the latter afford important information which could not be obtained from the former. A very common expression with the four-unit, educated colour-blind is that of calling certain colours greenish purples, or purplish greens. This observation is explainable enough when we consider the psycho-physical units which they possess. In the four-unit, violet and green are adjacent units, and so in a similar manner to the six-unit, who have a blue-green, the four-unit have a violet-green. I have already mentioned that it is very difficult to find a pure violet or blue; that objects of these colours nearly always reflect or transmit some of the red rays of the spectrum, and are, therefore, really purples. As the four-unit cannot distinguish scarlet from crimson, they class the whole of the purples and violets together, and call them by the name of the majority, purple.

It is interesting to note how the details of the psycho-physical theory are borne out by these cases. Thus blues, as a rule, are classed with greens, not greens with blues. In the painting, in the first case, the blues were represented uniformly by green. Again, the chief mistake he made in describing the complementary colours was that of calling the complementary of yellow, dark green.

Three-unit.

Individuals belonging to this class are markedly colour-blind, and are detected occasionally and imperfectly by many of the tests in use. Figure 5 of the frontispiece represents the spectrum as marked out by this class of the

colour-blind. They see three distinct colours in the spectrum, red, green, and blue (violet). These colours gradually pass into each other, and the three-unit can usually mark out the bands readily enough. They put the junction of the red and green at the middle of the yellow. The junction of the green and blue is put in the blue of the normal-sighted—not so much in the blue as the four-unit, but about the same distance as the five-unit. A colour-blind, who is acquainted with the spectrum, will often try to mark out an orange band, at the same time remarking that it is extremely difficult to do so. This orange band, when marked out, occupies about one-third of the green, the yellow, and orange of the normal-sighted. When it is marked out they are dissatisfied with it, and generally come to the conclusion that it is an unnecessary distinction, and that the red passes gradually into the green without the intervention of any other colour. They usually say at once that they see three colours in the spectrum. Their modified unit (red-green) is the one which gives them the most trouble. Bright yellows are recognized by their luminosity; but the browns cannot be distinguished in this way. Many three-units have remarked to me that red-green would be a far better name than brown, and they frequently use this term.

Green is a distinct colour from red to them; and, when asked if there is any similarity between the colours, they say "No," very decidedly. When asked which there is the most distinction between, the green and the blue, or the green and the red, they say that the distinction is most marked between the green and the red.

They only see three colours, and the varying shades of black and white. They therefore have a large number of superfluous colours. They regard the classification of

the normal-sighted as being unnecessarily complex, and full of hair-splitting distinctions. The two-unit colour-blind judge almost entirely by shade, whilst the three-unit are guided considerably by colour. They will never mistake their fundamental colours, red, green, and violet, but classify the others in the following way. Orange, yellow, yellow-brown, and red-brown will be put with red. Some yellow-browns will be put with red, others with green. Blue will be put with violet or green.

The modified unit red-violet is the one which gives them most trouble. The different hues of red-violet will be classified according to the relative proportions of the violet and red. When the violet or blue is in excess the colour will be put with violet; when the red is in excess the colour will be put with red; when the red and violet are about in equal proportions the colour will be put with green—that is to say, green will be put with its complementary rose.

The three-unit confuse some greens, purples, and grays. In the same way as a mixture of red and yellow gives rise in the normal-sighted to a sensation of orange, a mixture of red and violet gives rise in the three-unit to a sensation very similar to green, in conformity with the third law of colour-perception.

No. 120 is a bright green by day; but by gaslight appears purple to the normal-sighted. The three-unit, however, still see the colour as green by artificial light, and match it with a colour similar to 59 (green), which, to the normal-sighted, appears a very fair match by day.

It must not be supposed that the three-unit will mistake all greens, grays, and purples; in fact, in the majority of cases, they will not, and may pick out only greens to match with IV. and VI., especially when examined by daylight. An examination by artificial light very con-

siderably increases the mistakes of the colour-blind, though scarcely adding to the difficulty for the normal-sighted. By gaslight a three-unit may say that 124 (green) and 125 (gray) are exactly alike; whilst by daylight he has only put greens with the tests IV. and VI.

Several mixtures of colours make gray to the normal-sighted; but a gray, to be mistaken for green or rose by the three-unit, must consist of green, plus rose—that is, be a colour reflecting an approximately equal number of rays from the red and violet psycho-physical units. Then, as a mixture of red and violet gives rise to a sensation of green, the addition of green (though altering the character of the colour considerably to the normal-sighted) only increases its green character to the three-unit. The different compositions of colours which appear similar grays to the normal-sighted, may be brought out by photography—one gray may come out white, another black. I have photographs of a very large number of colours, which show this very well.

I had to construct a test strictly in accordance with these facts, in order to exclude the three-unit from the marine and railway services. I obtained a purple glass which was most opaque to the green rays of the spectrum (as shown by the spectroscope), and neutral glass which was almost opaque to the orange, yellow, and blue rays of the spectrum. In testing the three-unit, I have generally had all these glasses called green. The purple glass spoken of is the rose-purple used in the Classification Test. The colour was a very indifferent one as a colour, and I found that I could obtain the same results with a better purple, which could be made redder by the use of the neutral glasses.

Greens and purples which have been confused are often distinguished on comparison, the purples being put accord-

ing to the preponderance of the blue or red into the blue or red group.

It must be clearly understood that green is not mistaken for purple or gray; but purple and gray are occasionally mistaken for green. I have never found green wrongly named, and many grays and purples are named correctly. A three-unit usually expresses a decided opinion as to the nature of a green which is shown him; and it is evident that he sees it as a colour, and not as a shade of gray. There is no more reason in assuming that because a three-unit matches a certain green with a certain gray that he sees both as gray, than there is in saying a normal-sighted person sees green as gray, because these two colours look alike when viewed through a green glass.

In examining the three-unit we notice how the effects of contrast are exaggerated. The psycho-physical colour units are larger than in the normal-sighted, and so, if a change be produced by contrasting two colours, it is evident that the change will be greater than it is for the normal-sighted. It will be noticed that marked changes in colour are produced by contrast, to the three-unit, when no change is evident to the normal-sighted.

Many colour-blind persons belonging to this class will escape detection by Holmgren's test. This is more liable to occur if the blue-green wools be omitted in the first test, as Holmgren suggests. They will rarely fail to pass if they be allowed to watch a number of other persons going through the test, as in Holmgren's method of testing a number of persons, or if they have had any previous practice with the wools. An intelligent colour-blind person is often able to recognize colours by differences which, though trivial, are constant.

The following case illustrates this class, and how very inefficient Holmgren's test is for their detection.

D. A., a professional man, well acquainted with colour-names, told me that he felt he must be colour-blind, to a certain extent, as colours changed to him when they did not to other persons. He found most difficulty with colours by gaslight.

I. Spectroscopic Examination.

I. Solar Spectrum.—He saw three definite colours in the spectrum. The junction of his green and red was at the junction of my yellow and green. The junction of his green and blue was on the blue side of my blue-green junction. His red was shortened to an extent equal to one-tenth of the whole of the red. The termination of his violet corresponded with mine. He thought I was laughing at him, when I asked if the green had any resemblance to the red.

II. Lamplight.—This made an extraordinary difference in the spectrum to him. He said that with the exception of a small portion of green close to the blue-green junction the remainder of the green had become orange. The position of the blue-green junction he now put at a point which corresponded to mine. I put out the light and showed him the solar spectrum. He at once saw the green as before. I then lit the lamp again, and told him to cover up his eyes, and then, taking his hand away, to look straight at the green and name the colour. He said at once that it was orange, and there was a little green at its junction with the purple.

II. Classification of Colours.

I. Daylight.

Group 1. *Black.* Black.
2. *Red.* Red.
3. *Orange.* Gold, yellow-brown, and orange.
4. *Yellow.* All light colours. Yellow, brown, gray, and greenish yellow
5. *Gray.* Gray and purple-brown.

6. *Brown.* Brown and gray.
7. *Violet.* Violet and purple.
8. *Pink.* Rose-red, rose, and gray.
9. *Blue.* Blue and violet.
10. Blue and blue-green.
11. *Green.* Green and blue.

In this classification the most marked mistake is that of putting rose and gray together.

In Group 8 there were many reds similar to Holmgren's test, II. *b.* But there were no pure reds—that is to say, they all reflected a certain amount of blue or violet light.

II. Gaslight.—He now confused pure greens and pure grays. He matched a purple with a blue-green, and also confused blues and purples. He distinguished the reds easily from the greens and browns.

The piece of silk which changes from green in daylight to purple by gaslight he recognized as green by daylight; by gaslight he said that the colour had altered very little, and that it was still green, though it had changed to purple to me.

III. Test with Holmgren's Wools (*Daylight*).—This, in chronological order, was the first examination which I made in testing him. I gave him the test green to match, and he picked out the correct colours as rapidly and as easily as a normal-sighted person. I then told him to pick out all the greens. This he did, and the only mistake he made was that of putting three blues with the greens, and omitting one or two blue-greens.

IV. Test by Painting.—He painted a picture by daylight, which is a very fair copy of the original. The following are the mistakes which he made:—

An apple which was orange gradually passing into yellow; the orange part he represented by red, the lighter parts he represented by yellow. The greens were badly matched. In the one case he made them too yellow, and

in the other too blue. A yellow, shaded with gray, he represented by green. Orange-browns he represented by pure browns, and blue by blue-violet, and yellowish gray by pink. To make sure that none of the mistakes were due to carelessness, I went over each portion of the picture with him, and he was perfectly satisfied with the copy he had made. I then showed him the two pictures by gas-light, and he said the difference between the two became more distinct—namely, the brown was not red enough; the green leaves not dark enough; and a portion of the apple too red. There should have been more yellow. The remainder, he said, matched exactly.

V. Test as to Perception of Complementary Colours.—I tested him with shadows coloured by contrast, and he named the colours of the shadows correctly—red, pure green, and blue-green glass being used. The blue glass gave him most trouble, as he did not know what to call the shadow. That produced by yellow glass he called correctly blue.

E. A., Physician.—He had been aware for many years that there was something wrong with the way in which he saw colours. He knew the names of the various colours, but found difficulty in using them, because the name which applied perfectly in one case did not seem to apply in another. In other cases, his friends were able to see differences which he could not see. He has always found great difficulty in matching colours, but he could arrange shades easily enough. When, as a student, he was shown a spectrum, he was unable to make out the seven classical colours. There seemed to him to be only four—red, yellow, green, and blue,—and he found it necessary to learn the others by rote. He said he always found great difficulty in distinguishing blues from greens. He has mistaken a brown for a green, but never a red for a green. He has

mistaken a yellow for a red, and a drab for a green. A red fire appears yellow to him.

I. Spectroscopic Examination (*Lamp Spectrum*).—He saw three distinct colours—red, green, and blue. He also thought he saw yellow, but was very doubtful about it. He gave the junction of the red and yellow at the junction of the orange and red. He gave the junction of the yellow and green at the point of union of the yellow and green. He put the blue-green junction slightly into the blue of the normal-sighted. His spectrum, both for bright light and light of diminished intensity, was not shortened in the least, being exactly the same length as mine.

II. Classification of Colours (*Daylight*).—He said that pink is more like violet than red, and that blue and violet were very much alike. He picked out a deep purple-violet and a blue of the same shade, and said that they were exactly alike. He confused greens and browns, and also classed reds, rose, and some browns together. He found great difficult with one colour, a brown. (It is not represented in my Pocket Test, but is a colour midway between 60 and 67.) He said it looked brown when he put it against the greens, green when he put it against the reds.

It will be noticed that this colour is as nearly as possible one corresponding to the point of union of his red and green psycho-physical units. He made the following groups:—

Group 1. *Reds.* Red, rose, brown, purple, gray, and fawn.
2. *Yellows.* Yellow and orange.
3. *Greens.* Green, blue, yellow-brown, buff, purple-brown, and gray.
4. *Blues.* Blue, blue-green, violet, and purple.
5. *Violets.* Blue, violet, and purple.
6. *Browns.* Yellow-brown, buff, gray, and red-brown.

7. *Black.* Black.
8. *White.* White, very light pink, and very light yellow-green.

He put one or two shades of rose with group 3, but afterwards removed them to the reds.

III. Examination with Pocket Test.

1. *Daylight.*

I. *Orange.* 76, 54, 109, 99. Yellow-brown and orange.
II. *Blue.* 33, 9, 77, 93, 129. Violet.
III. *Red.* 36, 95, 116. Red.
IV. *Blue-green.* 11, 51. Green.
V. *Pink.* 21, 31, 52. Rose.
VI. *Green.* 15, 6, 53, 98. Green.
VII. *Light green.* 70, 94, 112. Yellow-green, green and olive-green.
VIII. *Lake, Purple-blue.* 3, 66, 55, 108, 117. Blue, violet, and blue-green.

It will be noticed that there are very few mistakes in this record, in fact, so few that an inexperienced examiner might pass him. I have, however, inserted this record in order to show one of the difficulties met with in examining the colour-blind. If the examiner were to force the examinee to go on picking out colours, the latter is almost sure to do so under protest, or to absolutely refuse. The probability is that a person who omits colours in the above way, *is* colour-blind. Positive evidence may be obtained in the following way. One of the most prominent omitted colours should be taken, and the candidate required to match it.

Acting on this plan, I asked him to match 120 (green). He said it was a brown, and well matched by 60 (brown). I asked him about 59 (green), but he said this was a green, and did not match 120.

He said II. was a pinky blue—that is, it appeared to have a shade of red in it. He then turned to a Scotch plaid, and said, "There is a typical blue, which I should

not mistake." The colour was a bright violet, which would have matched II. very fairly.

2. *Gaslight.*—On being shown a pure green he was uncertain whither it was a blue or a green, and matched it with a blue-green.

Shown a purple (a colour midway between 31 and 103), he called it green, and matched it with a green very similar to 80. He also confused brown and purple-brown. Shown a red containing a small amount of violet, he called it an orange, and matched it with a crimson.

IV. Test by Painting.—I painted for a copy two squares of Prussian Blue, one light and one rather dark. I then gave him Prussian Blue and Crimson Lake to match them with, and subsequently Gamboge. When he had made the matches, he was very uncertain about their accuracy, saying one minute that there was not the slightest difference, and another that there was. He was more satisfied with the match of violet and blue than the match of green-blue and blue.

V. Examination with Lantern Test.—Tested with lantern and coloured lights at a distance of fifteen feet. Called ground-glass, pink. Tested with coloured glass slides, the ground-glass slide being in front, named standard red, standard green, green, yellow, and standard blue correctly. Called a pale blue glass, green; and a pink glass, yellow. Tested with neutral glasses, called 9, 10, and 11, green; 12 red. Named ribbed glass correctly.

Tested with neutral glasses in combination with the standard red and green. Recognized red under all circumstances. Recognized red and green in combination with 9 (No. i. neutral glass). Failed to distinguish green, with 10, 11 and 12 (neutral glasses Nos. ii., iii. and iv.). He said that he could see the light, but that no colour could be seen. Showed no sign of confusing red and green.

VI. Test as to Perception of Shade (*Daylight*).—I tested him very carefully as to his power of matching shades of colour, and found that his matches agreed with mine.

VII. Test as to Perception of Complementary Colours (*Daylight*).—I gave him a coloured glass, and told him to look at the light transmitted through it for half a minute and then at a piece of white paper. In the first column is the colour of the glass; in the second the name which he gave to the complementary. In each case he saw a complementary.

Pure red	White
Blue	Yellow
Yellow	Blue
Blue-green	Yellow
Orange-red	Very light blue
Pure green	Very light blue

F. A., aged 24.—This gentleman knew that his colour-perception did not agree with that of the normal-sighted, and had carefully noted many of his mistakes. The most distinct colours to him were yellow, green, and blue. Reds seemed to run into yellows; and many colours which most people called red seemed to him yellow—such, for instance, as the glow of a red fire. It always seemed to him that the leaves of a small border-plant (*pyrethrum*) were yellow, whereas they are really yellowish green. He called a mauve hyacinth, blue. Once, when he was at an evening party, there where two sisters dressed exactly alike in pink dresses. He made a note in his programme that one was in pink, the other in yellow. Afterwards he could not tell which was which. He said he could always distinguish the railway signal-lights. He had difficulty in making up his mind with regard to colours. After the lapse of a year I again asked him his opinion

with regard to colours. He said that he found least difficulty with blue. Red and blue were the most distinct colours. He found difficulty in distinguishing light reds and light greens from yellows. He had mistaken a dark green dress for black. He thought that yellows would be better named if they were called reddish greens.

I. Spectroscopic Examination (*Gas Spectrum*).—Shown field containing red and green, recognized these as distinct colours, and named them correctly. Saw three colours in the spectrum—red, green, and blue. Said there was more difference between the red and green than between the green and the blue. Gave the junction of the red and green at the point of union of the yellow-green and green of the normal-sighted. Said the red gradually passed into the green without the intervention of any other colour. Gave the junction of the green and blue fairly correctly, if anything slightly in the blue. He found great difficulty in making up his mind as to the exact point. With regard to the length of his spectrum for bright light, the red was shortened one-third, the violet slightly. No increased shortening for light of diminished intensity.

II. Classification of Colours (*Gaslight*).—He made the following groups :—

Group 1. Pink, red, and rose.
2. Red, pink, orange, yellow, and crimson, and one light brown.
3. Pink, yellow, buff, and yellow-green.
4. Rose, pink, brown, and purple.
5. Green, light blue, purple, purple-brown, gray, and brown.
6. Green, light blue, purple, gray, and brown.
7. Olive-green, brown, slate, red-brown, yellow-brown.
8. Blue and green.
9. Brown.
10. Blue-green, green-blue, blue, violet, purple.
11. Very light pink, brown, gray, and rose.
12. *Blacks.* Black and dark red, rose, brown, and blue.

III. Examination with Pocket Test.

1. DAYLIGHT.

I. *Red.* 7, 12, 25, 36, 67, 76, 104, 109, 111, 123. Orange, red, and brown.

II. *Blue.* 9, 16, 24, 33, 49, 55, 68, 93, 108, 129. Violet, blue, and blue-green.

III. *Red.* 7, 12, 67, 62, 104, 127. Red, orange, and rose.

IV. *Green.* 32, 51, 53, 92, 122. Blue-green and green.

V. *Mauve.* 21, 31, 56, 63, 71, 79, 103, 107, 127. Rose, blue, purple, and violet.

VI. *Green.* 15, 53, 75, 94, 124, 100, 101. Green.

VII. *Orange.* 5, 14, 58, 99, 89, 113, 126. Yellow-green, yellow, and orange.

VIII. *Purple.* 16, 40, 41, 45, 65, 68, 77, 106, 129. Blue, violet, and rose.

On being asked, he said 120 was green, and gave 6 as a match. I asked how 59 matched 120, he said it was a better match still, and also added 80. I asked him if 111 and 112 (orange-brown and olive-green) were alike. He replied that he could not see any difference between them.

2. GASLIGHT.

I. *Red.* 7, 12, 19, 25, 36, 52, III., 54, 67, 76, 87, 99, 104, 116, 111, 123. Orange, red, red-brown, yellow-brown, rose, and yellow.

II. *Blue.* 2, 24, 33, 40, 49, 55, 68, 93, 106, 129. Blue-green, blue, violet, and purple.

IV. *Bluish gray.* 2, 32, 45, 56, 53, 63, 64, 65, 77, 81, 84, 86, 103, 106. Blue-green, green, blue, violet, and purple.

V. *Pink.* 21, 31, 52, 71, 107, 127, 130. Rose, pink, and blue.

VI. *Green.* 6, 11, 51, 53, 75, 100, 101. Green.

VII. *Orange.* 5, 14, 58, 89, 113, 126, 128. Yellow-green, yellow, orange.

VIII. *Purple.* 9, 16, 24, 45, 56, 65, 68, 92, 108, 129. Blue, blue-green, purple, and violet.

IV. Test for Twin Colours (*Gaslight*).—These matches only refer to single colours. Because a colour-blind person puts a certain rose silk with a green, it is no reason why he should confuse all shades of rose and green or even colours appearing to the normal-sighted exactly the same as those which he has confused.

The following colours were a match in all respects.

Bright yellow-green and rose silks.
Light blue and violet.
Deep blue and violet.
Myrtle-green and yellow gas-green.
Two shades and tints of green.
Green and gray.

The rose was the lighter colour of the two, and similar to 107. The yellow-green was a deeper shade of 113. In the case of the blues and violets, the violets were slightly lighter in shade. In the case of the myrtle-green (VII. is the exact colour) and yellow gas-green (a lighter shade of 78) the latter was considerably darker than the former. Viewed through a standard blue-green glass both colours looked identical in shade and colour. He said 100 and 101 were exactly alike, and might have been cut from the same piece of wool. He said 124 and 125 were exactly alike.

V. Examination with Lantern Test.—He distinguished red from green easily under ordinary circumstances, and when these colours were combined with the neutral glasses. Neutral glasses Nos. 9, 10, and 11 he called green. The very dark neutral glass No. 12 he called red. He called a light blue glass, green. He called a purple glass similar to the rose-purple of the Classification Test, green; and the yellow glass, red. A few months later I examined him again, with the following result. He called—

1B, 1A, 6 + 2, and 12 + 1A	Red
12, 3, 4, 7, 11, 9, 10, 12 + 4, 12 + 1B, 12 + 2, 12 + 3, 12 + 5, 10 + 5, and 11 + 5	Green
5, 5 + 4, and 9 + 5	Blue
2	Orange
6 and 6 + 4	Purple
8	Yellow
12 + 6	Bluish green

It will be noticed that in this examination he called

the combination 12 + 1B, green. On account of the shortening of the red end of the spectrum he could see very little, if any, red in the combination.

G. A., aged 27.—This gentleman had always found difficulty in distinguishing colours. He was perfectly cognizant of his defect. The chief difficulty which he experienced was in distinguishing reds from browns, and browns from black. When at his office one day, he wrote one half of a letter in red, and the other half in black ink. He was with great difficulty convinced of the error which he had committed. He finds great difficulty in recognizing reds at a distance. He has often found that he cannot see holly berries when they are quite visible to other persons. As he approaches the tree, however, the red berries suddenly appear amongst the green leaves. On getting still nearer the tree, the colours appear more distinct. He particularly remarked on the peculiarity of the colour suddenly springing into view. He had often tried to distinguish the signal-lights on a railway at a distance, but found that he could not do so. When he was close to them, however, he could distinguish the colours easily enough. He was convinced that he would make a very dangerous engine-driver. He related several instances of how he had mistaken browns for blacks. The following will serve as an illustration. He ordered some programmes for a concert to be printed on paper with a brown edge. When he received the sample, the edge appeared to him the deepest possible black. He went to the shop where he had ordered them, and said, "What do you mean by sending me black-edged programmes?" The man protested that the edging was brown, so he pulled the programme out of his pocket, and said, "What do you call that but a black?" The man said at once that it was

brown, and this was confirmed by appealing to another person. He has also mistaken a very dark blue for black.

I. **Spectroscopic Examination** (*Gaslight Spectrum*).—He saw three distinct colours in the spectrum, red, green, and blue. The red and green looked quite different except where they joined. The centre of the point of union was at the junction of my yellow and green. The red end of the spectrum was shortened to an extent equalling about one half of my red. The violet end was shortened to an extent equalling about one-tenth of my violet. The brightest part of the spectrum corresponded to the centre of my yellow-green. On first marking out the spectrum he marked out an orange which included my orange, yellow, and yellow-green. He recognized colours of low intensity when in the centre of the spectrum. I also tested him with a blue of low intensity near the blue-green junction, and he recognized it.

II. **General Classification of Colours** (*Gaslight*) :—

Group 1. *Red.* Red, orange, brown, rose, and purple.
2. *Orange.* Orange and deep yellow.
3. *Yellow.* Orange, yellow, and greenish yellow.
4. *Green.* Green, brown, and gray.
5. *Blue.* Blue-green, blue, violet, and purple.
6. *Pink.* Light rose and light brown.
7. *White.* Very light colours. Brown, white, rose, and gray.
8. *Black.* Black, dark brown, and dark red.
9. Purple.
10. Rose, gray, buff, and light green.
11. Brown.
12. Red-brown.
13. Brown.
14. Pink.
15. Rose.
16. Yellow-green.
17 Buff, yellow-green, and gold.
18. Brown.
19. Rose.
20. Brown.

He was not able to give definite names to groups 9 to 20.

He matched the changeable silks which appear purple and purplish gray to the normal-sighted by gaslight with olive-greens and grays, which would have matched these silks very well by daylight. Shown some wool matches by a two-unit, at once distinguished the red from the green and brown, but did not distinguish between a match of brown and green. Thought a colour-match made by another three-unit correct. The match was a blue-violet and a blue. Pointed out the mistakes in a picture painted by a two-unit.

III. Examination with Pocket Test (*Daylight*).

I. *Red.* 76, 104, 123, 85, 111, 112, 116. Orange, green, and brown. He said that 111 and 112, orange-brown, and deep olive-green were exactly alike.

II. *Blue.* 9, 24, 33, 49, 55, 65, 77, 93, 106, 129. Violet, blue, and purple.

III. *Red.* 36, 37, 67, 85, 87, 107, 116, 127. Red, brown, orange-brown, and pink.

IV. *Green.* 2, 11, 19, 23, 30, 32, 42, 43, 50, 51, 64, 91, 102, 121, Blue-green, green, brown and gray.

V. *Pink.* 2, 12, 30, 42, 50, 64, 73, 79, 107, 127. Blue-green, red, gray, and rose.

VI. *Green.* 13, 19, 34, 38, 53, 80, 98, and 120. Brown, gray, and green.

VII. *Yellow.* 5, 14, 54, 58, 89, 99, 109, 113, 126, 128. Yellow, buff, and orange.

VIII. *Blue.* 3, 33, 40, 45, 56, 68, 74, 77, 108. Blue, violet, gray, and blue-green.

He put with 1—15, 34, and 80, green, brown, and gray.

IV. Examination with Lantern Test.—Shown 11 + 7 (neutral iii. and ground glass). Called the colour first red, then green. Shown 12 + 4 (neutral iv. and standard green) said that the light had no colour. Shown 12 + 3 (neutral iv. and pure green), said the light was red. Called yellow, orange. Called a pink glass, green and dirty yellow.

He showed no tendency to confuse the red and green when uncombined with the neutral glasses, and even in the mistakes made above he remarked that the colour was really a red-green, in which the red predominated in the case of the pure green. In the case of the neutral glass iii., he said that the colour was such an exact mixture of red and green that he could not tell which it was.

V. Test by Painting (*Gaslight*).—He painted a picture very carefully. At first sight this picture appears to be a very good copy of the original; in fact, more than one normal-sighted person has remarked that he could not have painted the picture as well.

On looking into the picture, however, all the three-unit mistakes can be seen. I was with him the whole of the time that he was painting the picture, and his remarks and method of procedure were characteristic. This, as well as the other paintings which I have mentioned, were painted after the manner described in Chapter XI. He was given about forty colours on a series of plates, and so could be guided by colour only. He first painted a brown cat, green. After he had done so, he remarked that the cat in the original was a reddish green, so he painted red over his green, and this has made a very fair match. One portion of the cat which was gray in the copy he has left green. In another place he has represented light brown by green. A pinky ground he has represented by a light olive. Yellow-green in one place he has represented by yellow. Every speck of red has been correctly represented, and the greens have been represented in each case by green, with the exception of the single instance mentioned above. Blues and yellows have been correctly represented. I then showed him a picture painted from the same copy by a two-unit, and he pointed out the mistakes which had been made.

Sir William Ramsay, F.R.S.—He said that he only saw three colours in the spectrum. Yellow and orange did not appear to him as definite colours, but as transition colours between red and green. After a paper of mine on Colour-Blindness had been read at the Royal Society, one of the Fellows (a three-unit) kindly marked out the spectrum as it appeared to him. Sir William Ramsay was under the impression that the spectrum had been marked out correctly.

He said that the neutral colour between the red and the green (the yellow and orange) had an exactly similar appearance to that of a red-clover field in full blossom. He said that pigment yellows looked much more like definite colours than the yellow of the spectrum.

I. Spectroscopic Examination (*Gaslight*).—He saw three colours in the spectrum—red, green, and blue. His spectrum commenced and terminated at the same points as mine did. The junction of his red and green was in the centre of my yellow. He said that the red gradually blended with the green, the intermediate colour being admirably expressed by being called "reddish green."

The junction of his green and blue was at a point corresponding to the junction of the yellow five-sixths with the blue sixth of my green.

II. Examination with Classification Test (*Gaslight*).

I. *Yellow*. Orange, yellow, and brown.
II. *Lavender*. Violet, purple, and gray.
III. *Red*. Red, crimson, and orange.
IV. *Green*. Green and blue.

Also told to make groups of yellow and blue—

Yellow. All light colours. Red, orange, yellow, greenish yellow, and brown.
Blue. Blue and green.

With test II. all six grays were put. When I told him what he had done he put a gray by the side of test II.,

and then said that it had become green. He then took an olive-green, and putting it beside the gray, said that the latter had now become purple. The gray was moderately dark, and did not appear to change colour to me in the slightest degree. Having put the olive-green and the test II. a few inches apart, he laid the gray across them. He then said that the end which was resting on the green was purple; the end resting on the violet, green; and the portion between the two neutral. The wool appeared gray throughout to me. He said that he had often found difficulty in deciding whether a colour was purple or green when seen in the distance or background of a picture. He also found difficulty in painting foliage in which purple shaded into green. He called both neutral glasses, green. I showed him some pieces of changeable silk, some of which look purple by gaslight, others gray. He said that they were all purple.

On being told that he had put red, crimson, and orange together, he made three groups, but each group contained some of each of the three colours.

III. Examination with Pocket Test.

1. Daylight.

I. 7, 12, 19, 21, 36, III., 67, 76, 99 (?), 104 (?), 107, 111, 116, 123 (?). Pink, brown, rose, red, and orange.

2. Gaslight.

II. 33, 9, 16, 65, 68, 77, 93, 103, 114, 129. Violet.

III. I., 7, 12, 21, 107, 123 (?). Orange, pink, and rose.

IV. 2, 11, 15, 51, VI., 53, 80 (?), 84, 92, 94, 100, 124. Green.

In matching III. he said that he had taken great care to avoid pinks.

IV. Examination with Lantern Test.—He named red and green correctly under all circumstances, either alone or in combination with the neutral glasses. He called 2, "brownish red;" 10, "yellow flame, surrounded by misty

blue;" 11 + 5, "orange;" 9, "green;" 11, "green;" 12, "brownish red;" 12 + 7, "red."

I then tested him with feeble lights at various distances, from a few yards to a furlong. He never confused red and green, and could distinguish them at as great a distance as I could. He found great difficulty with the neutral and yellow glasses, and confused them with red and green.

I have a number of paintings by persons belonging to the three-unit class. In the case of educated persons the paintings are very much more accurately done than those by the two-unit. In none of these paintings has red been mistaken for green, or *vice versâ*. The following will serve as examples, as this method of colour-matching gives such accurate results.

H. A.—Picture painted by daylight. Yellow represented by red in several places, blue by blue-violet, the greens by duller and bluer greens, the remaining colours correctly.

J. A.—Picture painted by gaslight. Orange represented by Crimson Lake, green by blue, gray by greenish yellow, orange and gray by crimson, blue by green.

K. A.—Picture painted by gaslight. Blue and blue-green represented by green, purple by green, the remaining colours correctly.

L. A.—Picture painted by gaslight. Brown represented by green, blue by green, brown by purple, crimson by orange.

It is curious to note in this picture that in one part the brown was shaded with red. The brown in the copy was represented by green, but the red shading was put in as red.

M. A.—Picture painted by gaslight. Greenish blue represented by blue in one place, and in another place

by green, orange by crimson, green by purple, brown by purple.

N. A.—Picture painted by daylight. Blue represented by green, yellow by red, pink by yellow-brown, yellow-brown by greenish yellow.

O. A.—Picture painted by gaslight. Gray represented by blue, gray by brown, red by yellow-brown, yellow by yellowish gray, yellow-brown by purple-brown.

P. A.—Picture painted by daylight. Blue represented by blue-violet, green by blue, yellow-brown by red.

Q. A.—Picture painted by daylight. Yellowish green represented by greenish blue, green by blue, yellow by red, yellow by greenish yellow, blue by green, pink by brown, yellow-brown by orange-brown, red by orange-brown.

R. A.—Picture painted by daylight. Blue by blue-violet, dark orange by crimson, red by crimson, green by bluish green, orange-brown by yellow-brown.

The case of **E. A.** is an example of three-unit colour-blindness, uncomplicated with shortening of the spectrum. The cases of **F. A.** and **G. A.** show the complications due to a shortened spectrum. All, however, agree in the main —that is to say, their vision is truly trichromic, and the three typical colours are never confused with each other. In the numerous cases of three-unit colour-blindness I have examined, I have never succeeded in making the examinee mistake red for green. They will usually laugh at such a mistake as ridiculous. An exception must be made when a red is mistaken for a green, on account of shortening of the spectrum. That shortening of the spectrum is the cause of red being mistaken for green may be demonstrated in the following manner. Let both colours be examined through a coloured glass which is opaque

to the shortened portion of red. It will be found that both colours will look alike, in many cases appearing identical in hue and shade when viewed in this way. In painting it is just the same; these persons are able to produce a very fair copy, and take care to paint every speck of red correctly.

Their classification of colours is entirely different from that of the two-unit, and perfectly characteristic. The three-unit use Crimson Lake as a red, whilst the two-unit regard Crimson Lake as a very similar colour to Prussian Blue, and rarely use either.

It will be noticed that confusion colours were not put with Holmgren's test-green (VI.), even under the circumstances of difficulty produced by the Pocket Test. In fact, only greens were put with VI., and with each of the other colours more mistakes were made. This shows how unsatisfactory this colour is for a test.

Two-unit.

The cases which come under this head form the class of the ordinary red-green blind. It is under this head that nearly every one of the recorded cases may be classed. Vision, as far as colour is concerned, is dichromic, the neutral point being situated at the junction of the blue and green of the normal-sighted. A colour-blind person belonging to this class, on being shown a spectrum, usually says that it is made up of two colours, yellow and blue, the one gradually passing into the other. The brightest point of the spectrum, when it is not shortened, is at the yellow, about the position of the D line, just as it is in the normal-sighted. The colours which are described as being most representative of each of the bands are the yellow of the buttercup for the yellow, and the blue-violet of the corn-flower for the blue; in fact, just

the colour which corresponds to the central point of each unit.

Then, if any of the rays which fall within one unit be mixed with those which fall within the other, gray is the result. Therefore, violet and red, instead of making a crimson to the two-unit, make a gray which is indistinguishable from the gray made by blue and green. The two-unit cannot see any difference between Crimson Lake and Prussian Blue.

Figure 6 of the frontispiece represents the spectrum as marked out by a simple two-unit colour-blind. Red is, however, not the colour seen for the first unit; but I have represented the first unit of all as red, for the sake of uniformity. The centre of this unit corresponds to the yellow of the normal-sighted, and this is, therefore, the most representative colour. Most of the cases of two-unit colour-blindness are complicated by a shortened spectrum, either at the red or the violet end, for bright light or light of diminished intensity.

A neutral band may or may not be present in the green.

In the simplest case of two-unit colour-blindness there is an unshortened spectrum and no neutral band.

The progressive steps from this to complete colour-blindness are shown in Figs. 7, 8, 9, and 10 of the frontispiece.

The vision of the two-unit colour-blind is psycho-physically dichromic—that is to say, they see two true colours and gray. In the simple two-unit cases, red, orange, yellow, and green are seen as one colour, blue and violet as the other. The presence of a neutral band causes the colours corresponding to this portion of the spectrum to be perceived as gray. Therefore, the more extensive the neutral band, the more colours will be classed as gray.

No. III. in my Pocket Test is practically a pure red, though it reflects a small amount of violet light. This is of no consequence. Nos. 36 and 95 are pure reds, and are classed by the colour-blind with III.

Nos. 78 and 94 are represented by the two-unit as similar colours to 95. These two are the brightest possible greens. Scarlet and grass-green appear very similar to the two-unit, and they find great difficulty in distinguishing a scarlet coat lying on the grass.

The following case is one of considerable importance, and the reader is advised to study it very carefully. It is a case of simple two-unit colour-blindness, with a spectrum of normal length and no neutral band. As might be supposed, this case was one which I sought for from the commencement of my investigations; but, to show that these simple cases are not common, I may mention that I had reached my 101st case of colour-blindness before I was rewarded. Two-unit cases are common enough; but there is either shortening of the red or the violet end, or, if the spectrum be of normal length, then there is a neutral band in the blue-green.

I have given the facts as obtained; but I do not see how they can bear any other interpretation than that the man had simple uncomplicated dichromic vision.

S. A., aged 26.—He is a shrewd and intelligent man, one of a family of thirteen, five of whom died young. Of the eight remaining, five are men and three are women. None of the family have ever taken any interest in colours; but, as far as he can tell, none of them have ever shown that they were colour-blind. He has never taken any interest in colours, having had very little to do with them. Has never made any obvious mistakes in naming colours, and so did not know that he was colour-blind. The names

that are ordinarily given to various coloured objects seemed to him to suit them well enough. Examined as to the names of the colours of well-known objects, nine times out of every ten he gave the correct answers, using terms like purple, gray, and brown, in addition to the names of the primary colours. This examination showed that he was well acquainted with colour-names, and, therefore, that none of the mistakes made were due to ignorance. I first asked him what were the objects from which he took his ideas of colour. He answered, grass for green; the bark of a tree and the earth for brown; the sky on a fine day for blue; blood for red. He readily distinguished the difference in colour of some lichen growing on the bark of a tree, and named both correctly. He gave the correct colour-names of a number of flowers.

He also gave the colour-names of a large number of other coloured objects. The following were the mistakes he made. He said the upper surface of the leaf of the Aucuba Japonica was brown, with yellow spots. Said the under surface was green. This was, with one exception, the only leaf which he named wrongly. Said the orange glow of a coal fire differed in colour. He said that the brightest glow was yellow; where this glow was covered with incandescent white ash, green; where the glow was dull, red. The glow really differed very slightly in *colour* at the points indicated. He called yellow bricks, red, and the sky, pink. The colour of the sky was a pure gray, due to fog and mist. He called the white petal of an orchid, pink; dirty yellow paint on a door, green; some bright yellow paint, seen at a distance, gray; some yellow-green petals and leaves yellow; said the colour of a person's complexion was white, shaded with purple or blue. He named black and red ink correctly. I showed him a piece of half-burnt paper. He said the dark brown most

charred portion was brown; but the light brown, least burnt portion, red. He said that some carrots were red, others dark yellow.

Yellow and blue were his two most definite colours. His best examples of yellow were the colour of an orange, a dandelion, and a primrose; his best examples of blue—the colour of the blue sky on a stormy day, seen between two clouds, and the colour of a violet.

The chief effect of gaslight was to alter the colour of the greens: some colours (emerald green) which looked green by day looked blue by gaslight; others (yellow-greens) which looked green by day looked red by gaslight.

I. Spectroscopic Examination.

i. *Daylight.*—Spectrum of normal length He saw two colours, yellow and blue, gradually passing into each other. The junction of the two was at the normal blue-green junction. No neutral band.

ii. *Lamplight.*—Spectrum of normal length. He saw two colours, yellow and blue, gradually passing into each other. The junction of the two colours was at the normal blue-green junction. The brightest and most typical point of yellow was at the junction of my orange and yellow. The brightest and most typical point of blue was a little into the violet, just beyond the junction of my blue and violet.

II. Classification of Colours.

i. Daylight. Wools, glass, cards, silks, and velveteens being used.

Group. 1. Yellow, yellow-green, and orange.
2. Orange, yellow, and yellow-green.
3. Blue-green, gray, and crimson.
4. Red, rose-red, orange, and yellow-brown.
5. Rose red, crimson, and purple.
6. Brown, gray, and orange.
7. Deep red, green, and brown.
8. Olive green, pure green, brown, and gray.

9. Yellow-green, yellow-brown, and yellow.
10. Orange-brown, yellow-brown, green, and purple.
11. White and very light shades of pink, green, brown, and gray.
12. Yellow, light brown, green, and gray.
13. Blue, green, blue-green, and pink.
14. Yellow-brown, orange-brown, and dark olive-green.
15. Green, purple-brown, and gray.
16. Yellow-brown, purple-brown, blue-green, and gray
17. Blue-green, blue, purple, pink, and gray.
18. Blue, violet, and purple.
19. Blue, violet, and purple.
20. Black, and very deep shades of purple, brown, and violet.

ii. Gaslight.

Group. 1. Orange and yellow.
2. Orange, yellow, and pink.
3. Brown and olive-green.
4. Red, orange, rose, and purple.
5. Yellow, green, gray, brown, and purple.
6. Green, rose, gray, and brown.
7. Red, rose, and brown.
8. Red, rose, brown, and olive-green.
9 Browns.
10. Brown and green.
11. Green, brown, and gray.
12. Yellow, green, pink, brown, and gray.
13. Yellow, green, pink, purple, and white.
14. Yellow-green, pink, purple, brown, blue, and gray.
15. Blue and green.
16. Blue, green, violet, gray, and black.
17. Green, purple, and gray.
18. Green, brown, gray, and purple-brown.
19. Green, blue, and violet.
20. Green, purple, and gray.
21. Green, blue, purple, brown, and gray.
22. Green, blue, brown, and purple.
23. Green, blue, and violet.
24. Green, blue, violet, purple, brown, and black.

In making both these classifications it was evident that he was influenced by the two qualities, colour and shade, in about an equal degree. Thus several of the groups contained exactly the same colours, but a shade darker or

lighter. In the same way, light shades of a colour were not put with darker shades of the same colour. The luminosity of the colours was also a factor in the classification.

III. Examination with Pocket Test.

1. Daylight.
   - I. *Scarlet.* 76, 70, 54, 89, 99, 123, 109, 104. Orange, yellow-green, and yellow-brown.
   - II. *Blue.* 33, 24, 49, 9, 65, 68, 77, 106. Violet and blue.
   - III. *Red.* 36, 67, 104, 87, 95, 116, 94, 112. Red, orange, brown, and green.
   - IV. *Green.* 50, 73, 86, 125, 84, 31, 11, 42, 30, 102. Green, gray, light blue, and rose.
   - V. *Purple.* 2, 32, 56, 63, 71, 81, 130, 79, 103, 86, 105. Blue-green, blue, violet, and rose.
   - VI. *Brown.* 75, 102, 96, 38, 91, 100, 84, 125. Green, brown, and gray.
   - VII. *Yellow.* 5, 58, 89, 99, 113, 126, 14. Yellow-green, yellow-brown, and orange.
   - VIII. *Blue.* 24, 16, 9, 33, 45, 52, 77, 65, 106, 129, 68. Green-blue, violet, blue, and rose.
2. Gaslight.
   - I. *Red.* 7, 76, 54, 99, 104, 116, 123. Red, orange, and yellow-brown.
   - II. *Green.* 33, 40, 51, 56, 74, 94, 106. Violet, blue, green, and gray.
   - III. *Red.* 19, 12, 38, 54, 76, 99, 116. Brown, red, yellow-brown, and orange.
   - IV. *Green.* 2, 11, 33, 40, 56, 68, 98, 106, 124. Blue-green, green violet, blue, and gray.
   - V. *Red.* 19, 12, 38, 54, 76, 99, 116. Brown, red, yellow-brown, and orange.
   - VI. *Green.* 11, 32, 56, 75, 81, 103, 124. Green, blue, and purple.
   - VII. *Red.* 5, 12, 39, 58, 62, 89, 99, 116. Yellow, red, brown, and orange.
   - VIII. *Green.* 15, 20, 55, 93, 106, 129. Green, blue, and violet.

IV. Examination with Classification Test.

1. Daylight.
   - I. He first took in his hand a good many yellows and yellow-greens, but ultimately, with the exception of the light red glass, put only orange with the test.

II. Violet, blue, purple, and blue-green.
III. Red, rose-red, and orange.
IV. Green, greenish blue, stone, and gray.

2. Gaslight.
I. Orange, yellow, and pink.
II. Violet, purple, green, and blue. (Test IV. was put in this group.)
III. Red and crimson.

V. Examination with Lantern Test.—I will give the results of two examinations. The second examination was made after an interval of nearly four months, during which time he had been studying colours.

Ex. 1.—Called pure green in combination with the ground glass, yellow; ground glass, white; plain flame, purple. Named red, standard green, yellow, and blue in combination with the ground glass correctly. In naming neutral with ground glass, he called 9, red; 10, yellow; 11, red; 12, red. He called the combinations of 12 with 2, 1A, 3, 4, and 5, respectively, red.

He called the ribbed glass, first time, white and green; second time, white and red. The white was the flame. He called No. 11, in combination with 3 and 4 respectively, purple. He called the combination of 2 and 11, red and blue. The red was the flame.

Ex. 2.—On being shown the coloured slides alone, he named all correctly with the exception of the yellow, which he called, light red. He named ribbed and ground glass correctly. He called 9, 10, and 11, green; 12, red; and the combinations of 12 with red, pure green, standard green, and blue, respectively, red.

VI. Examination with Holmgren's Wool Test.

i. *Daylight.*—When first examined he put eighteen wools with the test green. This group consisted of green, brown, dove, stone, and gray.

When he made the above selection, he had not been

shown which were the colours that he should put with the test green. Feeling sure that I could teach him to pass through this test, I gave him the following instructions, having picked out the four shades of the test green.

1. You are only required to pick out four wools.

2. These wools form a series from light to dark. There is only one of each shade.

3. Pay especial attention to similarity of colour and no attention to similarity of shade.

He at once grasped the idea, and the first time picked out three of the correct greens and a red-brown, about which he said he was doubtful. The second time he went through the test very rapidly, and picked out the correct colours and those only. As he did not touch the confusion-colours, it would have been impossible for the most expert examiner to have said that he was colour-blind by this test. He took the test green to the pile, and, without taking any of the colours from it, carefully compared the test green with the other colours. When he felt sure that he had found one of the right colours he took it out, and so on until he had picked out all the colours correctly. In choosing the colours he displayed no hesitation whatever.

ii. *Gaslight.*—He found greater difficulty in picking out the correct wools than he did by daylight, but ultimately succeeded. He first picked out a number of confusion-colours in addition to the correct wools, and then rejected them one by one.

VII. Test by Painting.—He painted no less than seven pictures after the manner described in Chapter XI. These pictures were painted under various conditions of light. The mistakes made are similar to those made in the classification of colours. In one picture, painted by gaslight, he has represented yellow-green by red, gray by violet, blue by

violet, blue by green, pink by yellow, yellow by red, gray by olive-green, blue by purple, and yellow-green by yellow-brown. In another picture, painted by gaslight, he has represented blue-gray by purple-violet, orange by crimson, yellow by brown, pink by yellow, violet by blue, green by purple-violet, green by orange-brown, red by orange-brown, blue by greenish blue, brown by rose, and gray by blue-green. In another picture, painted by daylight, he has represented blue by violet, green by brown, red by orange-brown, yellow by yellow-green, red by green, gray by purple, yellow-brown by red, pink by greenish yellow, blue by blue-green, and yellow-brown by rose.

VIII. Test for Twin Colours.

i. *Daylight.*—He distinguished the factors in combinations by other two-units easily enough. I gave him a set of wools, and told him to pick out those which were exactly alike in every respect. He made pairs of the following colours: yellow-brown and orange-brown, orange and greenish yellow, purple and blue, gray and pink. As far as shade was concerned they were exactly alike.

ii. *Gaslight.*—He was first examined with the pairs mentioned above, and found that they were no longer twin colours. He made twin pairs with the following colours—purple and blue, green and greenish gray, buff and brown.

IX. Test as to Power of Distinguishing Shade.—I examined him very carefully as to his power of distinguishing shade, both by daylight and gaslight, and found that his perception of shade was similar to mine. He first arranged about 150 wools in a series from light to dark, paying no attention to colour. In all cases his decision corresponded with mine. He saw all the spectral colours when they were reduced to the lowest degree of luminosity visible to me.

X. Test as to Perception of Complementary Colours.—I first tested him with shadows coloured by contrast. The shadow was formed by the interposition of a penholder between a coloured glass and a piece of white paper. He said that the shadow was coloured in each case. He named the colour of the shadows when blue and blue-green glass were used, correctly. When pure green, red, or yellow glass was used, he said the shadow was coloured "purple."

He was then tested with coloured cards, looking at a card for a minute and then at a piece of white paper. In each case he saw a complementary colour. He said that the complementary of both yellow and green was purple, and the same kind of purple. He called the complementary of red, light blue, and named the complementaries of pink, blue, black, gray, and white, correctly.

I also tested him in a number of other ways, but the results obtained only confirmed the facts recorded above.

A careful examination of the above case shows how the facts elicited confirm the theory of psycho-physical perception. Here is a man who plainly sees only two colours definitely, and yet it is evident that his vision is not dichromic in the sense that it would be if there were only two colour-sensations. It is evident that he saw differences of colour besides the two colours yellow and blue. He saw as much difference between red and green as the normal-sighted see between blue-green and green. Accurate observation would not enable a person to judge between colours, when different materials were used, by the relative luminosity. The way in which he named and classified colours showed that he appreciated what colour is, and judged by it. It was on considering the case in this way which led me to believe that I could educate

him to pass Holmgren's test. I thought that as Holmgren's test green is a pure green, the absolute psycho-physical unit of which this colour would form the centre, would lie wholly within the green. If this were the case, a two-unit would be able to see a difference of colour between yellow and green, and therefore would be able to keep clear of the confusion-colours. The result showed that this was the case. The size of the absolute psycho-physical units is also shown by the examination for twin colours.

T. A., Male, aged 58.—He was well acquainted with his defect of colour-vision, though he was not aware of the extent. He thought that the ordinary system of naming and arranging colours was unnecessarily complex, and certainly did not agree with his ideas on the subject. He could see no resemblance between the green of a paint, the green of the spectrum, and the green of the grass. Green paint looked very like the colour of dirt. He could distinguish red cherries from the leaves by the colour. It seemed to him that there were only two definite colours, yellow and blue, and objects of these colours formed the greatest contrast. The following objects were most representative of each of the colours, yellow roses and primroses for the yellow, violets and heart's-ease for the blue. He was specially interested in heart's-ease, because he often found both his colours contrasted in one plant.

He does not care for colour, *as colour*, in the least.

I. Spectroscopic Examination.

i. *Solar Spectrum.*—He was well acquainted with the colours of the spectrum, and had often used a spectroscope. He at once proceeded to mark out the seven orthodox colours. The length of his spectrum was exactly the same as mine. He marked off the red from the orange, and the

orange from the yellow fairly. In giving the junction of the yellow and green, he put the pointer in the centre of the green. The junction of the blue and green, he gave correctly. In giving the junction of the blue and violet, he put the pointer within a short distance of the termination of the violet.

ii. *Lamp Spectrum.*—He remarked that the lamp spectrum looked much redder that the solar spectrum. His spectrum was of normal length. He marked off the red from the orange correctly. In giving the junction of the orange and yellow, he put the pointer at the junction of the middle with the outer third of the orange. He gave the junction of the yellow and green at the centre of the green. In giving the junction of the green and blue, he put the pointer in the centre of the blue. The junction of the blue and violet he put at the centre of the violet.

iii. *Gas Spectrum.*—This examination was made several months after those just recorded. It was evident that he belonged to the class of the two-unit, but had given the foregoing answers on account of his knowledge of the spectrum. In testing him, therefore, this time, I took care not to let him see the ends of the spectrum until I had finished with the middle. I arranged the spectroscope so that half of the green, yellow, orange, and half of the red occupied the field. On being asked the colour, he said there was nothing but yellow; on being asked the next colour, he said he supposed it was green, but it appeared to him to have no colour. He then marked off a large neutral band, extending into the blue on one side and the green on the other, about equal distances. This neutral band in size was about one-tenth of the whole spectrum. He was not able to distinguish between the blue and the violet. The length of his spectrum was the same as mine for bright light and light of diminished intensity. The

most luminous part of the spectrum and the most typical yellow was in the yellow of the normal-sighted. The point of greatest intensity of the blue was at the junction of my blue and violet.

II. Classification of Colours (*Daylight*).

Group 1. Blue, violet, and purple.
2. Blue, violet, and purple,
3. Light pink and light brown.
4. Yellows.
5. Yellows.
6. Reds.
7. Blue-green and gray.
8. Dark rose, brown, olive-green, dark blue-green.
9. Yellow-brown.
10. Prussian blue.
11. Rose-red, red, and brown.
12. Red, rose, and brown.

Group 13. Red and brown.
14. Green, pink, and gray.
15. Green, blue, purple, and rose.
16. Blue, blue-green, and rose.
17. Rose, gray, and green.
18. Blue and purple.
19. Pink, olive-green, and brown.
20. Blue-green, gray, and brown.
21. Green, gray, and brown.
22. Green and gray.

In this classification only wools were used, and it will be noticed that green was not confused with red. The above classification should be compared with the results of the examination with the Pocket Test.

III. Examination with Pocket Test.

1. DAYLIGHT.

I. *Reddish orange.* 76, 54. Orange and yellow-brown.

II. *Blue.* 9, 24, 49, 33, 55, 93, 129, 106. Violet, blue, and purple.

III. *Brownish red.* 1, 19, 75, 116. Red, brown, and green.
He said 78 (bright green) was a similar colour, but there was more red in it. He also said 100, 101, (greens) were the same colour, but much lighter.

IV. *Gray.* 6, V., 73, 50, 30, 110, 127. Blue-green, sage-green, rose, and gray.

V. *Gray.* 50, 11, 31, 84, IV., 110, 127. Rose, gray, green, and blue-green.

VI. *Light brown, Chocolate-colour.* 8, 75, 91, 102, 96, 107. Green brown, gray, and rose.

VII. *Orange-yellow.* 99, 14, 89, 109, 113, 58. Yellow-green, orange, and yellow.

VIII. *Mauve.* 130, 108. Blue, crimson, and blue-green.

2. GASLIGHT.

I. *Orange.* 76, 54, 89, 99, 123, III. Orange, red, and yellow-brown,

II. *Blue.* 24, 49, 3, 9, 16, 55, 66, 92, 93, 106, 129. Violet, blue, blue-green, and purple.

III. *Red.* 54, I., 76, 89, 99. Red, orange, and yellow-brown.

IV. *Gray.* 2, 32, 33, 40, 45, 56, 65, 68, 77, 81, 103, 130. Blue-green, purple, blue, violet, and crimson.

V. *Gray.* 23, 21, 18, 19, 42, 43, 50, 30, 73, 63, 96, 79, 91, 127. Rose, stone, brown, gray, green, and violet.

VI. *Gray.* 30, 52, 78, 130. Green, gray, and rose.

VII. *Pale orange.* 89, 125. Yellow-green, yellow-brown, and gray.

VIII. *Blue.* 49, 24, 20, 16, 9, 3, 72, 97, 47, 108, 55. Blue, green, violet, purple, blue-green, and gray.

IV. Test by Painting (*Gaslight*).—I first asked him to criticize (by daylight) a painting by another two-unit, in which nearly every possible mistake of the simple two-unit had been made—namely, green had been represented by light red and brown; orange by yellow; blue-green by Crimson Lake; green by gray; rose by purple. He examined both the copy and the painting very carefully, and remarked that the latter was very well done and a perfect copy.

I then got him to make a painting from a different copy. He did so with characteristic mistakes—painting the hands, faces, and arms of children yellow-green, instead of light red; leaves and foliage sometimes green, sometimes brown; the reds, some with light red, others with brown; crimson as brown, and many more characteristic mistakes.

V. Examination with Lantern Test. — Tested with lantern and coloured glasses at a distance of fifteen feet. Tested with the slides presented singly. He called the pure green, orange; and No. 12, greenish. The standard red, standard green, ground glass, ribbed glass, and neutral

glasses (Nos. i., ii., and iii.) he named correctly. A pink he called orange; the yellow, orange; the blue, blue-violet; and a light blue, violet.

I repeated the test, with the result that he gave the same answers with two exceptions. He called the pure green, red; and a light blue, greenish.

Tested with ground-glass slide in front. He called the standard red, the yellow, a pink, and the ground glass alone, orange. He said the standard green had very little colour; if anything it was faintly greenish. The pure green he called red; the blue, blue; a light blue, green inclining to violet.

I then tested him with the standard red and green, in combination with the neutral glass No. iii.

He called the standard green "no colour;" the standard red, reddish. The standard colours being shown with No. 12, he called the green "no colour;" the red, green.

With the ribbed glass in front he recognized the standard red, blue, and green.

VI. Test with Polariscope (*Gaslight*).—Shown green and pink together. Said that they looked somewhat alike. The pink looked the darkest; whilst the green looked as if it were a yellow with a shade of the pink colour over it. Shown other colours, and made similar mistakes to those already recorded.

VII. Test as to Perception of Shade (*Daylight*).—I tested him very carefully as to his power of distinguishing and matching shades of colour with wools arranged in series. I found that his arrangement of shade was exactly the same as mine, both for colours of the same hue, and for those of different hues. He matched blues with violets, greens, and reds of exactly the same shade.

VIII. Test as to Perception of Complementary Colours (*Daylight*).—He was able to see after-images, and they

appeared coloured. I tested him with a vermilion book, and told him to point out the colour in my Pocket Test which the complementary resembled. He pointed out No. 2 (blue-green), a colour which matched the complementary seen by me very well. He said No. 2 was much darker than the colour he saw.

I then tested him with bright blue paper. He pointed out No. 5 (yellow). My complementary was more like No. 4 (buff).

With pink paper of the colour of V. he could not get a complementary colour. He said the paper appeared a little darker, but there was nothing like any colour to be seen. I saw a complementary of the colour of VI. (green).

IX. Accidental Colours.—On pressing on his eye, he saw no colour, only light. If he looks at the sun and then at a white wall he sees a black spot. This spot does not appear coloured or change colour, but simply fades away.

U. A., Male, aged 14.—He first found out that his colour-perception was defective in the painting-class at school. He was well acquainted with colour-names. He said leaves and grass look red; holly-berries and the leaves appear the same colour, only the berries look lighter. The lips and faces of men and women appear blue, like the sky. A crimson rose always appeared to him to be blue. An orange and a lemon appear of the same colour. Very dark reds, browns, and greens often appear to be black. The glow of a red fire appears yellow, not red. He can easily distinguish a sovereign from a shilling by the colour.

I. Spectroscopic Examination (*Gas Spectrum*).—He saw two distinct colours in the spectrum, yellow and blue. These met at the normal blue-green junction. There was

no neutral band, the yellow gradually passed into the blue. The bright spectrum was considerably shortened at both ends, the total amount of shortening being equal to one-tenth of the whole spectrum. This shortening was equally divided between the red and violet ends. The red was therefore diminished by one-quarter. The violet end of the spectrum was still further shortened with light of diminished intensity; but this was not the case with the red. He could perceive any portion of the spectrum internal to the limits of shortening when its intensity was reduced to such a degree that the light was only just visible to me.

II. Classification of Colours.

1. Daylight.

Group 1. Grass-green, orange, olive-green, yellow, and bronze.
2. Light blue, blue-green, rose, pink, violet, light brown, and gray.
3. Red, green, and brown.
4. Yellow, orange, green, and brown.
5. Rose, blue, blue-green, purple, heliotrope, and gray.
6. Yellow, green, gray, and orange.
7. Green and brown.
8. Blue-green, rose-red, and gray.
9. White, very light yellow-green, light-buff, green, and gray
10. Red, orange, yellow, yellow-brown, pure brown, yellow-green, grass-green, olive-green, cardinal, bronze, and boreal.
11. Violet, rose, blue, and purple.
12. Violet, rose, blue, blue-green, purple, and gray.
13. Blue, blue-green, green, purple, brown, and gray.
14. Dark red, red-brown, brown, black, granite, myrtle, and ruby.

The colours and materials used in this classification were very numerous. On this account the generic term of the colours has to be used; thus group 3 consisted of numerous reds, greens, and browns. Poppy, pure green, and pure brown fairly represent the group.

2. Gaslight.

Group 1. Green, gray, brown, and pink.
2. Yellow, pink, and gray.
3. Green, gray, and brown.
4. Rose, gray, and brown.
5. Green, blue, violet, and purple.
6. Green, blue, and purple.
7. Brown and olive-green.

Group 8. Blue-green, blue, violet, and purple.
9. Brown, red, and olive-green.
10. Blue-greens.
11. Browns.
12. Red and yellow-brown.
13. Reds.
14. Red, rose, and brown.

III. Examination with Pocket Test.

1. Twilight.

I. *Red.* III., 87, 76, 25, 85, 104, 123, 111, 112. Orange, red-brown, and olive-green.

II. *Blue.* 33, 49, 52, 24, 65, 68, 79, 66, 93, 106, 117, 129, 9, 16. Violet, blue, purple, and rose.

III. *Red.* I., 36, 37, 27, 57, 59, 88, 116, 119. Red, orange, brown, olive-green, and greenish gray.

IV. *Gray.* 7, 12, 6, 11, 18, 51, 62, 73, 91, 92, 110, 121. Blue-green, pink, gray, green, and rose.

V. *Light blue.* 50, 45, 40, 31, 32, 56, 63, 81, 86, 106, 127. Rose, gray, blue, and green-blue.

VI. *Green.* 19, 8, 38, 96, 100, 101. Green and brown.

VII. *Yellow.* 14. 5, 48, 58, 54, 99, 94, 89, 109, 113, 123. Yellow-green, yellow, yellow-brown, and orange.

VIII. *Blue.* 26, 52, 79, 108, 74, 30. Blue, gray, rose, and blue-green.

2. Gaslight.

I. *Red.* 25, 36, III., 67, 70, 76, 85, 104, 111, 123. Orange, brown, and red.

II. *Blue.* 9, 24, 33, 40, 56, 65, 68, 77, VIII., 106. Violet, blue, and purple.

III. *Red.* I., 1, 26, VI., 70, 76, 78, 87, 94, 104, 116, 123. Red, orange, brown, gray, and green.

IV. *Pink.* 2, 11, 18, 21, 23, 30, 31, 32, 42, 43, 50, 63, 71, 81, 91, 96, 115. Blue-green, green, rose, gray, violet, and blue.

V. *Pink.* IV., 11, 30, 56, 71, 79, 107. Rose, blue-green, green, gray, and blue.

VI. *Green.* 1, 30, 38, 78, 102, 116, 121. Green, brown, gray, and red.

VII. *Yellow.* 5, 10, 14, 58, 89, 99, 109, 113, 123, 126, 128. Yellow-green, yellow, buff, and orange.

VIII. *Blue.* 20, 27, 37, 41, 57, 69, 83, 114, 120. Blue, green, brown, rose, crimson, and purple.

IV. Test by Painting.—I have three pictures by this youth—one painted in broad daylight, one in twilight, and one by gaslight. He also made a special colour-match. These paintings, being very carefully done, are characteristic.

In the one painted by daylight all the blues are represented by violet. Green, red, brown, and yellow are confused with each other, and other characteristic two-unit mistakes have been made.

By twilight the mistakes made are similar, but not so marked. By gaslight all the two-unit mistakes were made. Olive-green and light red were used indiscriminately for the reds and greens.

I also got him to match vermilion with a mixture of gamboge and black. The colour-matches he made in this way were very similar to those made by another colour-blind person.

V. Examination with Lantern Test.—Tested with lantern and coloured glasses at a distance of fifteen feet.

(i.) With ground-glass slide in front. Named standard red, standard green, and blue correctly. Called the pure-green slide, orange, and the yellow slide, red.

(ii.) Named the ribbed white glass correctly, and recognized the standard red and green in combination with it.

(iii.) Called the four neutral slides, uniformly, green. He distinguished the standard red and green in combination with No. i. neutral glass.

With Nos. ii. and iv. he utterly failed to distinguish the red and green; he said the colour was a mixture of the two, a reddish green.

With No. iv. he could *just* see the light, but said that it had no colour in either combination.

VI. Test for Twin Colours.

i. *Daylight.*—I obtained exact matches between the following colours—

Blue and pink.
Navy blue and deep rose.
Blue and rose.
Myrtle-green and yellow grass green.
Myrtle-green and orange.
Bronze and orange.
Pink and drab.
Blue and violet.
Blue and rose-red
Slate and rose-red.
Maize and yellow.
Orange and grass-green.

Besides these, I obtained many twin colours belonging to the same class of colour, but differing slightly in shade or tint.

ii. *Gaslight.*—I obtained numerous matches by gaslight, and have worked the wools into letters and crosses on canvas. The chief are—

Scarlet, olive-green, and pure brown.
Orange and yellow-green.
Bright olive-green and emerald-green.
Yellow and light green.
Olive-green and sage-green.
Two shades of pink.

With the exception of the two shades of pink these all remained twin colours to him by daylight.

VII. Test with Changeable Silks.—These silks, which change very markedly in colour when viewed by artificial light, are represented in the Pocket Test by 119, 120, 121. Nos. 119 and 121 are gray by daylight; No. 120 a bright green. All appear purple by gaslight.

He said 119 was green, and matched it with a slate; 120, a red, and matched it with a bright green; 121, a

green, and matched it with a very light blue. By gaslight 119 and 120 changed colour; but 121 was still like the light blue chosen, and 119 and 120 had now become exactly alike, and were matched with a slate.

In addition to the above I had another changeable silk, in which the change from green to purple was still more marked. By daylight he called this a brown, and matched it with a scarlet. By gaslight he matched it with a very deep red.

VIII. Test as to Perception of Complementary Colours.—He could see complementary colours, and always named a colour corresponding to the correct portion of the spectrum. I tested him with shadows coloured by contrast, and in the following way. I gave him a piece of coloured glass and told him to look at the gas flame through it, with both eyes, for several minutes, and then at a piece of white paper. In each case he saw a colour, differing from that of the glass, on the paper, at which he expressed great surprise. The following are the answers he gave:—

Standard red ...	Green, yellowish green.
" green ...	Red, much darker.
Blue	Yellow, very bright.
Yellow	Pale blue, pink, a very fine colour.

IX. Test as to Perception of Shade.—His power of distinguishing shade was not very good. Unlike the two-unit previously recorded he put certain reds with black. All the mistakes made are accounted for by the shortening of the spectrum. Thus, in the twin colours, which were to him matches in every respect, the rose was considerably lighter than the blue with which it was put. Three different shades of scarlet were put together, as were six shades of claret. In the case of the violets, which were matched with blues, the former were very much the lighter in each case. Bronze was matched with a very much

lighter orange. It will be noticed that he put a yellow-green with a myrtle-green as exactly alike. The yellow-green was a very dark shade, the myrtle-green much lighter. On examining the two through a green glass which was opaque to the red rays, the two appeared to me identical in hue and shade. In considering colours internal to the red and violet, he was able to distinguish shades of the same colour in a far better manner.

The following account, given by Dr. Pole,* of his colour-blindness, is so explicit, that I will give it in his words.

"In the first place we see white and black and their intermediate or compound gray (provided from alloy with other colours) precisely as others do.

"Secondly, there are two colours properly so-called—namely, yellow and blue—which also, if unalloyed, we see, so far as can be ascertained, in the normal manner.

"But these two are the *only* colours of which we have any sensation; and hence the defect has been given by Sir John Herschel the scientific name of *dichromic vision*.

"But now comes the difficulty of the explanation. It may naturally be asked: Do we not *see* objects of other colours—such as roses, grasses, violets, oranges, and so on? And if we do see them, what do they look like? The answer is, that we do see all such things, but that they do not give us the colour-sensations correctly belonging to them; their colours appear to us varieties of the other colour-sensations which we are able to receive.

"This will best be explained by examples. Take first the colour red. A soldier's coat or a stick of red sealing-wax conveys to me a very positive sensation of colour, by which I am perfectly able to identify, in a great number

* *Nature*, October 24, 1878, p. 677.

of instances, bodies of this hue. If, therefore, the investigation of my experience ended here, there would be no reason to consider me blind to red, or as having any grave defect in my vision regarding it. But when I examine more closely what I really do see, I am obliged to come to the conclusion that the sensation I perceive is not one that I can identify separately, but is simply a modification of one of my other sensations—namely, *yellow.* It is, in fact, a yellow, shaded with black or gray—a darkened yellow, or what I may call yellow-brown. I find that all the most common hues of red correspond with this description, and in proportion as they are more scarlet or more tending towards orange, the yellow I see is more vivid.

"I obtain a further proof of this by the change of sensation when the hue of red is altered. I find that as the colour approaches crimson, the yellow element becomes fainter, and the darkening shade more powerful, until very soon the yellow disappears, and nothing but a gray or colourless hue is presented to my eye, although the colour is still a positive and powerful red to the normal-eyed. So that there is a hue of red which, as a colour, is absolutely invisible to the colour-blind.

"If I go on beyond this point, and take reds that pass from crimson towards the hue called Lake, I see my other colour come in—a faint blue, which increases till violet is reached, when it becomes more decided. Violet is understood, I believe, to be a compound of blue with red, and, accordingly, the red element being invisible to the colour-blind, violet hues generally appear to them only as a darkened blue. There are, however, examples where, from the red being very strong, the blue appears to lose its effect, and the impression given is colourless—black, or gray. They correspond, in fact, with the neutral red before described, although still called violet or purple by

the normal-eyed. This latter effect is much enhanced under the artificial light of gas or candles."

There are many points in this record which require comment. Dr. Pole says, writing of his not being able to distinguish scarlet from yellow or yellow-brown. "The explanation, I suppose, is that none of such reds are pure, they are combinations of red with yellow, so that I see the yellow element of the combination, while the true red element is invisible to me as a colour, and acts only as a darkening shade." Now Dr. Pole himself says,* that he was able to see the spectrum in its entire extent, and that he could not distinguish spectral red from spectral orange and yellow, therefore red is *not* invisible to him. He also sees a neutral band in the blue-green. Therefore he comes under the class of the two-unit colour-blind with an unshortened spectrum, but with a neutral band. With regard to the colours seen, he says, "The pigments Ultramarine and Chrome Yellow, or the parts of the solar spectrum near the lines D and F of Fraünhofer, excite the colour-sensations I am capable of, most fully and completely, and form with each other the strongest contrast it is possible for me to conceive."

Dr. Pole also speaks of violet being a compound of red and blue. Violet is not a compound of red and blue, but a primary colour, and differs from either in the refrangibility of the waves of light which give rise to it. It is easy to understand why the different colours mentioned by Dr. Pole appeared darker or neutral to him: the colour reflected rays which belong to both units; thus a mixture of red and violet to the normal-sighted appears as the modified unit crimson, whilst to the two-unit colour-blind it appears gray or one of the two colours considerably darkened.

* *Philos. Trans.*, vol. cxlix., p. 326.

The reason why red appears as a darkened yellow to the colour-blind is, that it is a much less luminous colour. Yellow is much brighter than red to the normal-sighted. In order to confirm this, I obtained several colour-matches, and the two-unit colour-blind matched a scarlet (vermilion) with a mixture of gamboge and black. The factors appear to me accurately matched as far as shade is concerned.

The following observations by Captain Abney and Major-General Festing are of importance.

They say,* after testing Dr. Pole by their method of colour photometry—

"In some cases of colour-blindness it does not seem as if there were any diminution in the range of vision, along the spectrum, as compared to that of normal sight. Such a case we had in Dr. Pole, F.R.S. From his paper it appears that with him the sensation of red is altogether absent, but that red appears to him as yellow. He described to us certain shades of orange as Yellow Ochre diluted or mixed with white or black. The red about C and below appeared to him as yellow mixed with increasing quantities of black. A very interesting feature in his case is that one part of the spectrum which we definitely determined to be at λ 5020, scale number 51, is to him absolutely neutral in colour. He describes all tints on one side of this point as being composed of blue, and on the other of yellow, mixed in each case with varying proportions of white or black.

"Dr. Pole is a most accurate observer; in very nearly every case did his three observations of intensity come to precisely the same point in the red. Fig. 6, plate 24, shows the comparison between his curve and ours. From this it would appear that there is a deficiency both in the red and the green. To us his neutral point appeared a

* *Philos. Trans.*, vol. clxxvii., p. 439.

cerulean blue, which to make white requires the addition of a large proportion of yellow.

"At 49, which is λ 5386 in the spectrum, the shadows seem of the same tint to Dr. Pole while to us at that point, the candle-light appeared Burnt Sienna, and the spectrum light emerald green, whilst the colours of the shadows appear to us the same at 46½ or about D."

Dr. Pole has kindly permitted me to give the following additional details with regard to his case.

He does not see a definite neutral band between the blue and the yellow. He has great difficulty in making out a neutral point. It is somewhere about halfway between *b* and F, but he has difficulty with the solar spectrum in determining the exact place.

He says, that he is able to match colours with regard to shade easily enough. I tested him with some wools which were very nearly alike in shade, and in each case he pointed out the darkest correctly. Shades of red and green, and red and violet were matched.

Examination with Pocket Test (*Daylight*).

I. 7, 8, 54, 76, 70. Pink, brown, yellow-brown, and orange.
II. 33, 49, 55, 77, 93, 129. Violet and blue.
III. I., 7, 8, 70, 67, 104. Orange, pink, and yellow-green.
IV. 2, V., 30, 50, 63. Green, blue, rose, gray, and violet.

On being asked the colour of 53 (a pure green), he said blue, but thought that the red on one side and the deep yellow on the other might cause it to appear blue. On shutting off these colours, he said it appeared neutral.

V. A., Clerk, aged 48.—He had been for a long time aware of his inability to see colours as others saw them. He said that he did not think he knew what colour was. He found especial difficulty with pink, blue and magenta.

They all looked like one colour. He also found difficulty in distinguishing greens from browns.

I. Spectroscopic Examination (*Gas Spectrum*). He saw two definite colours in the spectrum, yellow and blue The red end of his spectrum was shortened to an extent, equalling two-fifths of my red. There was a neutral band at the junction of the yellow and blue. This neutral band in size was equal to about one-tenth of the whole spectrum.

The end of his blue corresponded to the termination of my violet. The violet end of his spectrum was shortened for light of low intensity. When this portion was cut off with the shutter, he could see violet and green of very low intensity. When a very bright spectrum was used, by opening the slit, he said the neutral band appeared to move to the left (towards the red). I asked him to shut off the neutral band with the shutters. He marked off a band about three-quarters of an inch in size with my blue-green junction exactly in the centre. He said that the two colours seemed to dwindle away as they approached the neutral band. The colour of the neutral band was gray, not white. The brightest spot of the spectrum was exactly in the centre of the yellow.

II. Classification of Colours.

i. Daylight.

Group 1. Red, brown, dark green, dark blue-green, and gray. The reds and browns put in this group were much lighter than the other colours.

2. Orange, green, and light brown. He picked out a bright green as being almost of the same colour as the orange.

3. Yellow-green, orange, yellow, light olive-green, and yellow-brown.

4. Green, brown, gray, and red.

5. Green, light brown, gray, and light rose-red.

6. Blue, blue-green, and rose.

7. Blue-green and gray.

8. Rose-red, rose, blue-violet, and purple.

9. Blue-violet, and purple.

10. Dark green-blue, and bright rose.

ii. GASLIGHT.

Group 1. Red and brown.
2. Blue-green, gray, and dark rose.
3. Brown.
4. Rose, brown, and blue.
5. Red, rose, red-brown, and yellow-brown.
6. Red, rose, brown, and olive-green.
7. Red, red and yellow-brown.
8. Dark red, brown, green, and black.
9. Black.
10. Yellow and pink.
11. Brown and olive-green.
12. Brown and dark green.
13. Brown, gray, blue-green, and green.
14. Red-brown and olive-green.
15. Green and brown.
16. Orange, yellow, and light brown.
17. Yellow, white, light red, gray, and brown.
18. Buff and yellow-green.
19. Light green, brown, blue, and rose.
20. Sage-green and yellow-green
21. Blue-green and blue.
22. Brown, gray, and green.
23. Green, light blue, gray, and purple.
24. Yellow-green, light red, brown, and yellow-brown.
25. Light blue and brown.
26. Rose, brown, and yellow-brown.
27. Purple, violet, and blue.
28. Blue-green, blue, purple, violet-blue, and purple.

III. Test by Painting.—He painted a picture by gaslight, and, on going over the picture with him, he said that with two exceptions his picture was an exact copy. It is curious to note that the two exceptions were the two portions of the picture which were nearest to the original—namely, where he had represented an orange-brown by a yellow-brown, and a gray swan by too dark a gray. He remarked that the colour in the first case was not right, and in the second too dark. The following are the mistakes made. Green is represented by yellow-brown, red by black, green by black, blue by gray, pink by brown,

orange-red by green, red-brown by red, yellow by gray, green by brown.

Mr. Herbert Rix, Assistant-Secretary of the Royal Society, has kindly permitted me to publish the details of his case.

He has known for a long time that he cannot see colours properly. He has often mistaken greens and browns. His most definite colours are yellow and blue. Green looks a dirty indefinite colour; red looks like a dark yellow. He once matched a brown donkey by painting yellow over a blue ground. He was very surprised when told that he had made a green donkey. Red berries at a distance appear to be lost in the green leaves. He cannot see any difference between the colour of green lichen and the red tiles upon which it often grows.

I. Examination with Spectrum (*Electric-light Spectrum thrown upon a Screen*).—He saw two definite colours, yellow and blue. His red was shortened to an extent equalling about one-third of my red. It is probable that the real shortening was considerably more than this, because in a spectrum thrown on a screen the rays of light overlap to some extent. The violet end of his spectrum was not shortened. He marked out a colour which he called green; he said it was a very dirty colour. It extended from the middle of my blue to the middle of my green.

II. Examination with Classification Test (*Gaslight*).—He put with:—

I. Orange, yellow-green, yellow, light red, and pink.
II. Violet and green.
III. Red.
IV. Light blue.

III. Examination with Lantern Test.—Called 1A and

1B, red. Called 12 + 1B, first red then dark green. Called 9, 10, 11, and 12, respectively, green. Said 12 + 1A, was black. Called 2, and 3, yellow. Said 2 + 10, was red or green, he could not say which. Said 5, was blue or green, and 6, violet. Called 12 + 3, red, and 12 + 4, green.

W. A., Male, aged 50.—He mentioned to me that he was colour-blind in the right eye, and gave the following history. Before he was twenty-eight, he had a very keen perception of colours. But at this time he was working with the spectroscope, and being anxious to finish some observations he was making, he worked for eight or ten hours a day with the instrument. His observations were specially connected with the colours of the spectrum. When he had kept this up for a fortnight he found that he could not see with his right eye, which was the one he had employed in making his observations. He said a sort of brown moon appeared, and obstructed the field of vision of his right eye. He could see on each side and round this moon, but not through it. After fourteen days the moon disappeared, and he has had no trouble with his eyes since, with the exception of *muscæ volitantes* when he is out of health.

He then found that he had lost the power of distinguishing colours with his right eye. His condition, instead of improving, became more marked as time elapsed.

He was rather pleased, than otherwise, with the state of things, because he found that his power of distinguishing minute differences of form and size was greatly increased. He found that he was able to see lines in the spectrum which were not visible to him before, on account of the glare of the colour.

He is also able to see lines in the infra-red and ultra-

violet. Thus he can see the principal lines up to the line M in the ultra-violet, and from the line X in the infra-red. These portions of the spectrum did not appear coloured; the lines appeared as black on a dark gray ground.

A.—EXAMINATION OF RIGHT EYE (*Left Eye being bandaged*).

I. General Appearance.—The eye presented a perfectly natural appearance in all respects, being similar to the left eye. The peculiar look which is often seen in the eyes of colour-blind persons was not present. Iris brown.

II. Spectroscopic Examination.

i. *Solar Spectrum.*—He said the spectrum appeared to him as if there were a little red at one end, a little blue at the other and gray between. The red commenced at the B line of Fraünhofer. He can see A as a blacker line on a gray ground. Red practically ended at C, and this band of colour was uniform in intensity and did not vary like this portion of the spectrum did to the left eye. There was very little red to be seen after the line C, the colour rapidly fading into gray. This reddish gray ended at a point just before the line D at 46 on the spectrum scale—that is, at the junction of the orange and yellow of the normal-sighted. He said the red was much bluer than that seen with the left eye, and not at all of the character of a primary colour.

After 46 there was no colour to be seen, the spectrum appearing gray. This neutral band included the yellow and bright portion of the yellow-green of the normal-sighted. From 56 to the E line there was still no colour, but the gray was darker. From E to *b* there was a milky gray colour. This small band occupied the position of the centre of the green of the normal-sighted.

From *b* to F he can distinguish a blue-gray, but has much difficulty in making out a colour at all. This blue-gray increased in intensity and quality up to the G line, and after that faded, the colour ending at H.

ii. *Gas Spectrum.*—His brightest point of red corresponded to mine. This spectrum had a similar appearance to the solar spectrum, there being a little red at one end, a little blue at the other, and gray between. The length of the colour-spectrum was also similar; the red was shortened to a corresponding extent, and the violet about one-third.

The colours he described exactly as he did those of the solar spectrum, but, instead of telling me the line to which the colour extended, he moved the spectrum until the pointer of the eye-piece was exactly at the intended junction. The junction of his red and ash-colour was exactly at the junction of my orange and yellow. The junction of his ash-colour and blue-gray was about one-third into my blue. This band extended to within one-third of the end of my violet. The brightest and most typical point of his blue was situated at the junction of the middle with the blue third of my violet.

III. Classification of Colours.

i. *Daylight.*—All colours appear as if they were mixed with a considerable amount of gray, so that there is really very little difference between colours. Red objects look as if they were gray tinged with red, and blue objects gray tinged with blue. This appearance is quite different from that of the bright colour seen with the left eye.

Group 1. *Reds.* Scarlet, crimson, and rose.
2. *No colour, ash-gray.* Gray, yellow, light blue, brown, green and light-purple.
3. *Washed-out greens.* Blue and green.
4. *Impure blues.* Brown, gray, green, violet, blue, rose, and black.

I showed him a half-sovereign and asked him what it was. He replied very decidedly, "A sixpence." He at once recognized it when he took the bandage off his left eye.

ii. *Lamplight.*

Group 1. *Reds.* Scarlet, crimson, and rose.
2. *Yellows.* Yellow, light brown, and gray.
3. Purple and brown.
4. *Lavenders.* Dark yellow and brown.
5. Brown and gray.
6. *Blues.* Green and blue.
7. *Ash-colour.* Brown, gray, and violet.
8. *Blacks.* Dark red, dark rose, dark violet, brown, gray, and a light olive-green.
9. *Browns.* Brown and mauve.

He remarked that there was very little difference between the last three groups.

IV. Examination with Pocket Test (*Daylight*).

I. *Milky violet.* 12, V., 52, 76, 104, 36, 41, 45, 75, 62, 123, 127, 130, 107, 116. Orange, red, rose, green, and blue.
II. *Gray.* 3, 9, 16, 24, 33, 34, 49, 55, 66, 72, 80, 93, 97, VIII., 108, 129. Violet, blue, brown, green, and purple.
III. *Reddish gray.* 7, 36, 52, 76, 95, 116, 123. Red, rose, and orange.
IV. *Gray.* 2, 11, 15, 32, 45, 51, VI., 55, 64, 78, 81, 92, 94, 106, 122, 124. Blue-green, blue, and green.
V. *Lavender.* 8, 19, 54, 62, 79, 89, 109. Rose, brown, pink, and orange.
VI. *Gray.* 2, 11, 32, 51, 56, 75, IV., 84, 94, 106, 122, 124. Blue-green, blue and green.
VII. *Gray.* 73, 23, 54, 38, 39, 42, 43, 50, 90, 113, 115. Yellow-green, gray, yellow, yellow-brown, and red-brown.

He pointed out 45 (blue) as being like I. (orange), but it will be noticed that he has also put 45 with IV., which he said it was much more like.

V. Test by Painting (*Daylight*).—I set him to copy in water-colours a small German picture. He found no difficulty with the reds. He, however, made no distinction

between orange and red, but painted both indiscriminately with Crimson Lake. The yellows he did not perceive, and so omitted to represent them by any colour.

After he had finished painting, I made him compare each part, especially those parts which were yellow in the copy. He, however, said that both were exactly alike. The blues he painted correctly. Some greens he represented by a very feeble green.

He represented all the browns by mauve; thus a greenish brown monkey and the hair of a girl are both painted mauve.

I also requested him to make a copy of the spectrum, as it appeared to the right eye—first, with his left eye bandaged, and then with both eyes open. In the first case he represented the colours beyond his colour spectrum by a very dull blue; the red portion with a reddish brown; the blue as violet; the centre gray as gray. With both eyes open he represented his red as a dull reddish brown; his first neutral band as yellowish brown; the darker band as bluish gray; and, after that, the blue gradually fading away into gray.

VI. Examination with Lantern Test.—He was tested at a distance of fifteen feet from the lantern. When shown the standard red alone, he was doubtful about it, and said it was not a pure but a brick red. When a ground-glass slide was placed in front of the red glass, he recognized the colour as red. Tested with pure green, standard green, blue, yellow, and various depths of neutral glass, he declared uniformly that they had no colour. At the end of the series, he said that I had *not* shown him a violet glass.

He was able to recognize the red glass, even when I put various thicknesses of neutral glass in front of it, with the exception of the thickest glass which, in combination

with the red, though appearing a very bright red to a normal-sighted person, appeared black to him.

VII. Test as to the Perception of Shade (*Daylight and Gaslight*).—He matched, as being exactly alike in all respects, blues and greens which were of the same shade to my eyes. Tested with coloured cards, made matches which in shade agreed with mine except when either end of the spectrum was specially involved.

VIII. Test as to the Perception of Complementary Colours (*Gaslight*).—I tested him to find out whether he could see complementary colours. I tested him with the standard red, green, and blue glasses, but could not obtain the least evidence of a complementary colour. He looked through the coloured glass at a gas flame, and then at a piece of white paper, but did not see an after-image or colour of any kind. Tested with red, blue, and yellow cards with the same result.

Tested with a bright emerald-green card he saw a complementary, which he said was brick-red in colour. Tested with a pink card, he saw a gray complementary which corresponded to the sensation caused by green.

B.—EXAMINATION OF LEFT EYE (*Both Eyes being open*).

He said that, when he was looking at a colour with both eyes open, he felt that he was receiving the sensation of colour through the left eye. He said that he could see colours very well with this eye. He could see the lines in the spectrum, but not so well as with the right eye. Tested with Holmgren's wools, he matched the test-colours easily enough. Afterwards I was testing him as to shade with purples and violets. He separated these colours, but remarked that two purples, which were only reddish

violets, looked as if green were mixed with them. Subsequent examination showed that this eye belonged to the four-unit class of colour-blind.

I. Spectroscopic Examination.

i. *Solar Spectrum.*—Red commenced at A; orange at C; yellow at 46 of the spectrum scale, just before D; green at 56 of the spectrum scale. Blue commenced at a point midway between *b* and F. Violet commenced a a little before G at 119 of the spectrum scale, and ended about H.

He saw the spectrum gradually varying in colour from the red to the violet end, but saw no trace of a dark blue. He remarked that there was very little difference between violet and blue, only the former was darker. He added that he had marked out the yellow, as he knew it should be marked out; but it always seemed to him as if the orange extended to the right of the D line.

ii. *Gas Spectrum.*—Spectrum normal length. When giving the junction of the red and orange, he put the pointer in the centre of my orange. In marking out the junction of the yellow and green, he put the pointer a little into the green. He marked out an orange band; but, as he commenced his yellow band at precisely the point (as shown by the recording scale of the spectroscope) where he had left off the red band, it was clear that an orange band did not exist.

In marking the junction of the green and blue, he put the pointer at about the junction of the middle and inner (green) thirds of my blue. The pointer was distinctly surrounded by blue, there was not a trace of green or blue-green at this point.

I told him that the pointer was in the blue; but so certain was he that he had hit off the exact junction, that he called up several persons to support him, and

asked them where the pointer was. All without hesitation replied, "In the blue."

He gave the junction of the blue and violet about one-sixth into my violet.

II. Examination with Pocket Test (*Daylight*).

I. *Reddish orange.* 7, 36, III., 76, 95. Orange and red.

II. *Blue.* 9, 24, 33, 49, 55, 66, Violet, purple, and blue. When he came to 93 (a deep bright violet), he said, "That is violet, not blue."

IV. *Green.* 2, 15, 32, VI., 51, 53, 64, 75, 78, 80, 94, 100, 122, 124, Yellow-green, green, and blue-green.

III. Examination with Lantern Test.—He recognized red as red, even through the thickest neutral glass. Examined with the coloured glasses, the ground-glass slide being in front. He called the standard green, blue. When it was shown him with the thickest neutral glass in front, he said the colour was dark green. He named the pure green and neutral glasses correctly. He called the yellow glass, reddish yellow, and the blue, bluish green.

IV. Test as to Perception of Complementary Colours.—I tested him with coloured glass, in the manner previously described. He called the complementary of red, yellow; that of yellow, green; that of blue, yellow. Repeated trials gave the same result.

The following case, described by Professor Ramsay,* is of considerable interest. He says:—

"The first case is that of a gentleman who could not name any colour but blue. On being given an assortment of coloured wafers to arrange, he first singled out all the blue ones, and also a number of pink wafers, saying that these were all blue. The others he arranged, without any

* *Bristol Naturalists' Society's Proceedings*, vol. v., pt. ii., 1886–1887; "On Colour-blindness," by Professor W. Ramsay, Ph.D.

reference to colour, in an order which appeared to him to represent difference of shade—dark chocolate, red, and green being placed indiscriminately in one class, orange and light green wafers forming another, yellow and light gray a third, and white the last. To all appearance these colours struck his eye as more or less dark shades of gray. In monochromatic sodium light he arranged the colours in the same way, and said that to him they presented no change of appearance. He was incapable of distinguishing any colour in polarized light, and indeed denied that there was any difference in intensity of shade. Now, to a normal eye blue, appears darker, *i.e.* less illuminated, than yellow; but of course it is difficult to compare the relative shades of two wholly different colours. This gentleman was able to perceive light at the violet end of the spectrum, where a normal eye could see nothing; and his vision was much restricted at the red end. He could see a solution of sulphate of quinine in gaslight as coloured, and named it blue; by an ordinary eye the solution cannot be distinguished from water in artificial light."

This case is one of considerable interest. It appears to be a case of dichromic colour-blindness, with shortening of the red end of the spectrum and a lengthened violet end. The fact that he arranged colours by the monochromatic sodium light as he did by daylight, appears to show that ultra-violet rays are given off by burning sodium, and that it was by these rays that he recognized the blues. This case cannot be classed as an example of total colour-blindness, because he was able to distinguish blues; and he could, therefore, make two classes of colours—namely, those which were blue, and those which were not blue. Professor Ramsay tells me that this gentleman was a sailor, and he was noted for his power of being able to see a white light long before it was visible to other persons.

I have already referred to the fact that the red rays are the most penetrating of the visible spectrum; but from this it appears as if the ultra-violet rays were still more penetrating.

Total Colour-blindness.

The following case was related to me by an architect:—

X. A., Architect's Assistant.—He did not understand in the least what was meant by colour, and said that colours appeared to him simply shades of white and black. He had to use colours in making plans, but was guided by the name on the colour. One of the clerks, being aware of his defect, scraped off the names of the colours, and so, in a plan, he put Indigo where Crimson Lake should have been, and *vice versâ*. His friend had a house in which there were dark oaken timbers and light-orange coloured plaster. He asked, when looking at the house, why the plaster was so much darker than the wood. His friend told him that the plaster was very much lighter than the wood, but he would not believe it. In a photograph, which was subsequently taken of the house, the plaster came out much darker than the oaken timbers.

This case may or may not be one of total colour-blindness. From the facts given it is evident that he had very considerable shortening of the red end of the spectrum. This shortening must have extended nearly to the yellow to make a light orange appear darker than a deep yellow. The red element in Crimson Lake was not perceived, so this colour was mistaken for a blue.

The following case of total colour-blindness, described by Donders, is quoted by Joy Jeffries. He says—

"Professor Donders reported an interesting case of congenital total colour-blindness at the Heidelberg Ophthalmological Society, 1871. An educated young man of twenty-one years of age was totally colour-blind. Strong light blinded him: in moderate light he saw very well. He was myopic one-eighth, and read for hours without glasses. Out of doors all glasses which absorbed light without difference—even the brightest-coloured ones—were pleasant to him, because they reduced the light. In the dioptric spectrum of a gas-lamp his brightest part was between the spectral lines D and E, close to E: hence in greenish yellow. From here outwards towards the red end the light faded rapidly; towards the violet, at first slowly, then rapidly. By moderate illumination he lost less of the brightness of the spectrum on this side than towards the red end. With the polariscope, the complementary colour through the quartz plate appeared to him of the same colour. In turning the double-refractive prism he had a maximum of brightness at every ninety degrees, or equality of brightness, as if the quartz-plate was not there. He had the greatest difference when Donders himself saw purple and green; equality, when he saw yellow and blue. Trials were also made with Chevreul's chromatic circle."

The following is an epitome of the different classes of the colour-blind:—

Five-units see only five definite colours. They confuse orange-red and red, orange-yellow and yellow, rose-red and red, purple-violet and violet. They also confuse bluish green and green.

Four-units see only four definite colours. They confuse red, orange, and rose-red: greenish blue and green. They also confuse pure blue and violet.

Three-units see only three definite colours. They confuse red, orange, rose-red, and most yellows on the one hand, and blue, violet and purple on the other. They have a tendency to mistake rose, gray, and green. They confuse many browns and greens, and bluish greens and greens.

Two-units see only two colours. They confuse red, orange, yellow, and green on the one hand, and blue and violet on the other. They also confuse blue-green, purple, and gray.

One-units see only one colour.

CHAPTER XIV.

ACQUIRED COLOUR-BLINDNESS.

As a lesion in any part of the track from the eye to the brain may interfere with colour-perception, cases of acquired colour-blindness may be divided into two classes: A. Defects of colour-perception due to disease of the eye or optic nerves. B. Defects of colour-perception, due to some affection of the brain.

It is obvious that in those cases in which the visual acuity is markedly affected, the loss of colour-vision is only of secondary interest. We are chiefly interested from a practical point of view in those cases in which the visual acuity is not affected to such a degree as to compel a man to give up his employment.

Acquired colour-blindness has been described as an accompaniment of many diseases of the retina and optic nerves. The cases of acquired colour-blindness which are most common are those of central scotoma for colours, associated with atrophy of the optic nerve, or met with in cases of tobacco amblyopia. The following case illustrates the condition of central scotoma for colours.

Y. A., Male, aged 41.—He had been a very heavy smoker, and had given up work for eighteen months on account of his sight, which grew worse and worse. He said that he could not tell a half-sovereign from a sixpence

by the colour. He had often found difficulty in telling a half-crown from a penny by the colour.

There was central scotoma for both red and green in each eye. The scotoma for green was more definite than that for red.

I. Examination with Holmgren's Wool Test (*Daylight*).—I examined him in the ordinary way with Holmgren's Wool Test. He picked out the correct greens to match I. with ease.

II. Additional Examination with Wools (*Daylight*).—I then told him to pick out all the greens. This he did, but put several light blues with the group. I then gave him a violet skein (No. II. Classification and Pocket Tests) to match, and he put only violets with it. I then gave him a red (No. III. Classification and Pocket Tests) to match, and he selected only reds to put with it.

III. Examination with Pocket Test (*Daylight*).

I. *Orange.* 1, 7, 8, 12, 13, 19, 25, 76, 78, 67, 54, 89, 104, 99, 109, 123, 116. Orange, brown, red, yellow-green, and yellow-brown.

II. *Blue.* 33, 9, 16, 24, 49, 55, 64, 65, 66, 77, 93, VIII., 106, 129. Violet, blue, blue-green, and purple.

III. 1, 7, 8, 12, 13, 19, 67, 70, 76. 78, 94, 99, 111, 116, 123. Red, brown, orange, olive-green, and yellow-green.

IV. *Gray.* VI., 73, 91, 124, 125. Green and gray.

V. *Purplish Gray.* 3, 31, 5. Gray and rose.

VII. *Yellow.* 70, 76, 98, 99, 100, 113. Olive-green, orange, green, and yellow.

It will be noticed that the mistakes made are those of an ordinary two-unit colour-blind.

The following case, which is recorded by Samelsohn,* plainly points to the brain as being the seat of disease. It is an example of complete hemiopic colour-blindness. He says—

"A man, aged sixty-three, complained of affection of

* *Lancet*, Nov. 26, 1881, p. 918.

sight, which followed an apoplectic seizure. Right-sided hemiplegia was present at first; but nine months afterwards had lessened to a trifling weakness in the arm and leg, without loss of sensibility. Examination of the eye showed that the opthalmoscopic appearances were normal, and the acuity of vision unimpaired, excepting trifling presbyopia, slight weakness of the right superior rectus existed with corresponding diplopia above the horizontal plane. Since he complained of imperfect sight, even when the right eye was closed, the fields of vision were examined. On testing with a white object no defect could be discovered, even with a test-object of very small size. When, however, coloured tests were used, there was found to be a typical left-sided hemiopia for all colours, the loss began exactly at the vertical middle line. In the right half of each field every colour was seen, even in the smallest area, well up to the periphery; in the left half no colour could be recognized, even in a large area each appearing to be a dull grey. The same result was obtained on testing in the dark with lights tinted by passing through coloured glasses. Under treatment the paralysis of the superior rectus passed away; the paresis of the limbs and the affection of the sight remained exactly the same. Four years later the patient died, after a fresh attack of apoplexy; but, unfortunately, no *post mortem* examination was made.'

The following case, related by Dr. Wilson,* is an example of colour-blindness coming on after an injury to the head and concussion of the brain. He says:—

"Mr. B., who was introduced to me by Mr. John Struthers, lecturer on anatomy, studied here some years ago, and afterwards engaged in practice in Yorkshire. In November, 1849, he had the misfortune to be thrown from

* "Researches on Colour-blindness," by George Wilson, M.D., p. 39.

his horse, and was taken up in a nearly insensible condition, labouring under symptoms of concussion of the brain. He was confined to bed for months, and has now a very imperfect recollection of what transpired during the period; but he has kindly procured for me, from his medical attendant, Mr. Thom, of Dobcross, a statement of his condition whilst under his care. From this it appears that, after rallying from the collapse which immediately succeeded the accident, he suffered from severe pain in the head, delirium, mental excitation approaching almost to mania, loss of memory, and other symptoms of cerebral disturbance, which did not subside for many months. Eventually Mr. B. regained his health, and resumed practice. He is not so robust as before, nor is he capable of so much fatigue; neither is his power of mental application nor his memory so vigorous as it was previously; but he has wonderfully recovered from the serious accident which befel him. One sense, however, appears to have been irremediably injured. On recovering sufficiently to notice distinctly, objects around him, he found that his perception of colours, which was formerly normal and acute, had become both weakened and perverted: and it has since continued so.

"He has for the present resumed the study of medicine in Edinburgh, and has also allowed me to test his vision of colours freely. All coloured objects, he informs me, now seem strange to him. The rainbow is quite destitute of hue, appearing as a white semicircle against the sky, or as a lunar rainbow does to most normal eyes. This absence of colour in the solar spectrum, however, is largely due to the weakening of Mr. B.'s colour-vision: for certain of the tints of coloured objects held near to the eye are well enough distinguished, especially yellow and blue. Bright shades alone are pleasant to look at; dark shades

appearing "a mass of confusion" uncomfortable to the eye. Red and green in all their shades are undistinguishable from each other. These were Mr. B.'s conclusions concerning his own case, and I found them fully confirmed on trial. Bright blue and yellow he never mistook: red and green, I may say he never knew; and he put aside as incapable of definition all the more mixed or composite colours.

"In Mr. B.'s case the extent to which the power of the eye over colour has been altered is placed beyond doubt. Whilst formerly a student in Edinburgh, he was known as an excellent anatomist; now he cannot distinguish an artery from a vein by its tint. He was previously fond of sketching in colours; but since his accident he has laid it aside as a hopeless and unpleasant task. Flowers have lost more than half their beauty for him, and he still recalls the shock which he experienced on first entering his garden, after his recovery, at finding that a favourite damask rose had become in all its parts, petals, leaves, and stem, of one uniform dull colour; and that variegated flowers had lost their characteristic tints.

Mr. Struthers informs me that from the details communicated by Mr. Thom, it appears "that there was no fracture of the skull. It was a case of severe concussion followed by a long cerebral excitement, but not of an inflammatory type, apparently."

The following case of White Cooper's is related by Tyndall. He says—

"The sufferer was a sea captain, and, ten or twelve years ago, was accustomed, when time lay heavy on his hands, to occupy it by working at embroidery. Being engaged one afternoon upon a piece of work of this description, and anxious to finish a flower (a red one, he believes), he prolonged his labours until twilight fell, and

he found it difficult to select the suitable colours. To obtain more light, he went into the companion, or entrance to the cabin, and there continued his needle-work. While thus taxing his eyes, his power of distinguishing the colours suddenly vanished. He went upon deck, hoping an increase of light would restore his vision. In vain. From that time to the present he has remained colour-blind. Berlin worsted, with which he had been accustomed to work, he at once and correctly pronounced to be blue. He had a keen appreciation for this colour, and never made a mistake regarding it. Two bundles of worsted—one a light green, and the other a vivid scarlet—were next placed before him. He pronounced them to be both of the same colour. A difference in shade was perceptible; but both to him were drab. A green glass and a red glass were placed side by side between him and the window; he could discern no difference between the colours. A very dark green he pronounced to be black; fruits, partly of a bright red and partly of deep green, were pronounced to be of the same uniform colour. A cedar pencil and a stick of sealing-wax placed side by side were nearly alike. The former was rather brown; the latter, a drab. Electric light through a green glass, allowed to fall on a screen, gave him no colour; but only that portion of the screen was a little less intensely illuminated.

"Captain C. was assured that, previous to the circumstances related, he was a good judge of colours; so that, pronouncing on any colour, he had an aid from memory not usually possessed by the colour-blind. Indeed, he had an opportunity of *reviving* his impression of red. A glass of this colour was placed before his eyes while he stood before the electric lamp. On establishing the light, he at once exclaimed, 'That is red!' He appeared greatly delighted to renew his acquaintance with this colour, and

he declared that he had not seen it for several years. The glass was then held near the light, whilst he went to a distance; but in this case no colour was manifest; neither was any colour seen when a gas-lamp was regarded through the same glass. The intense action due to proximity to the electric light appeared necessary to produce the effect. Captain C.'s interest in this experiment was increased by the fact that the Portland light, which he has occasion to observe, has been recently changed from green to red; but he has not been able to recognize this change. The fare in the fore-cabin of a vessel of his own, which he now commands, happens to be sixpence; and he is often reminded by the passengers that he has not returned their change. The reason is, that he confounds a sixpence with a half-sovereign, both being to him the same colour. A short time ago he gave a sovereign to a waterman, believing it to be a shilling."

Another case of acquired colour-blindness is related in the chapter on the "Accidents which have occurred through Colour-blindness." The above cases of colour-blindness, due to disease or injury, support the view that colour-blindness is due to some defect in the brain. In many cases there was accompanying cerebral affection. The colour-blindness in these cases is similar to that of the congenital variety.

I have examined two very interesting cases of total colour-blindness. One, a woman, became totally colour-blind after ear disease. I examined her when she was regaining a certain amount of colour-perception. As we should theoretically expect she could distinguish between red and violet, the rest of the spectrum appearing gray. The other case was a signalman who had become totally colour-blind after tetanus. His visual acuity was partly 6/6. He had previously passed the wool test several times.

CHAPTER XV.

MISTAKES MADE BY THE COLOUR-BLIND.

As the reader who is not practically acquainted with colour-blindness would find great difficulty in making out to which class a colour-blind person belonged, until he had thoroughly mastered the preceding chapters, I will deal with the subject from another aspect—namely, that of the actual colours themselves. In this way an examiner, by referring to this chapter, will be able to make out the class to which a colour-blind person belongs, even if only one or two facts be known.

I. Non-perception of Certain Colours.—The confusion of any colour with black is an indication that there is either a shortened spectrum or a neutral band.

1. *Confusion of Red and Black.*—This indicates shortening of the red end of the spectrum. It may be met with in otherwise normal-sighted persons. When persons only find difficulty in distinguishing red from black at a distance, it is probable that the shortening is not very great.

The following letters appeared in the *Times*:—

"Sir,

"As one partially colour-blind, perhaps you will allow me to say a word in connection with the interesting leader in the *Times* of to-day, on practical vision-testing. I have been aware of a personal visual defect,

which I have tested on innumerable occasions for something like thirty years. But to me the coloured skeins of the wool-test is no test at all, for both reds and greens in all shades are unmistakable; and, although I have undergone this examination whenever an opportunity has presented itself, I have never tripped. Close at hand, reds and greens are to me as to other people; at a distance, however, my sense of colour, in regard to red especially, is all astray. Standing on the edge of a large field glowing with poppies, I see them up to about thirty or forty yards as other people see them; but beyond that distance they gradually merge into a neutral tint and become lost. Again, what is commonly called the pink may is glorious with colour when near at hand; but at some distance I see nothing but green leaves. A distant red light over a chemist's door appears to be a dull yellow, and the same applies to a red railway-signal. This seems to prove that sight in regard to correctly distinguishing colours and their shades may be normal close at hand, and defective at a distance. Had my vocation been that of a locomotive driver, I have no shadow of doubt that I should have passed the examination with coloured skeins of wool; and I am equally sure that, on the first opportunity, I should have driven my train and passengers to destruction.

"I am, sir, your obedient servant,

"A. W. T.

"January 23, 1890."

"Sir,

"As the question of colour-blindness is so important, and as the main point as to distance was so completely missed in the late discussion at the Society of Arts, will you allow me to corroborate the statements made in the letter of 'A. W. T.'?

"My late wife was partially colour-blind. She could not see at a distance the colour of a red railway-signal. She could not see the red coat of a soldier at two hundred yards distance; a bright orange-colour display of the aurora borealis was to her white. Yet when the objects were near she could distinguish colours perfectly. The red geraniums near my window she could see as well as I could; but those a hundred yards off were lost in the green. She could choose and compare coloured silks or worsted, and could paint well, and was a remarkably good colourist. And yet, like 'A. W. T.,' had she been put to drive a railway train she would have driven it to destruction.

"Yours truly,

"G. P.

"Richmond, Surrey, January 24, 1890."

2. *Confusion of Violet and Black.*—Confusion of violet and black indicates shortening of the violet end of the spectrum. If the violet be only indistinguishable from black at a distance, it is probable that the shortening is not very great. Thus **Z. A.**, a two-unit with shortening of the violet end of the spectrum, remarked to me that he could not distinguish a deep violet dress from black. It is obvious that the violet confused with black must be very dark, because substances of a lighter colour reflect or transmit other rays than the violet; whereas substances of a dark colour generally reflect only those rays which are peculiar to the colour that they bear.

3. *Confusion of Blue and Black.*—This variety of colour-blindness is much less common than either of the preceding two. It is met with in cases in which there is a large neutral band extending to the violet. All blues will appear gray, and a very dark blue will not be distinguished

from black. In addition to this it must be remembered that a dark pure blue, the colour of which is obvious enough by daylight, is not easily distinguished from black by gaslight by the normal-sighted.

4. *Confusion of Green and Black.*—Green is not easily distinguished from black by those two-units who have a neutral band in the blue-green. The green which they confuse with black will be a green, corresponding to the portion of the spectrum occupied by the neutral band. The green will really appear as a very dark gray, which can be distinguished from black by comparison, but under ordinary circumstances would be called black without hesitation. The larger the neutral band the greater the variety of greens which will be indistinguishable from black. In all these cases the greens will be dark for the reason mentioned, when speaking of blue.

5. *Confusion of other Colours with Black.*—In the two-unit any two colours taken from the two-units will make gray. It is obvious, therefore, that a dark purple which is confused with blue-green will also be confused with black.

II. Confusion of one Colour with another.—The cases that are included under this head may be produced by shortening of the spectrum or diminution in psycho-physical perception. The confusion of colours due to psycho-physical perception is caused by colours which appear perfectly distinct to the normal-sighted, being included in a single unit of the colour-blind. Confusion of colours caused by a shortened spectrum is due to the fact that coloured substances, as seen by the normal-sighted, reflect other rays than those of the colour which they appear. In these cases the colour which, to the normal-sighted, appears the lighter of the two will be found to reflect rays occupying the shortened portion of the spectrum. If these

two colours be viewed through a glass which is opaque to the rays occupying the shortened portion of the spectrum, they will appear identical in colour and shade.

1. *Confusion of Red and Green.*—This variety of colour-blindness has attracted more attention than any other. The confusion of red with green is essentially a mistake of persons belonging to the class of the two unit. For all practical purposes it is a mistake which is diagnostic of the two-unit. As it may be met with in other conditions, it is necessary that these should be mentioned. The three-unit are perfectly cognizant of red and green as colours, and therefore would not mistake the one for the other. If they were asked to name some hundreds of red and green objects they would give the correct answer in each case; but the following are the conditions in which they might mistake the one for the other. They recognize yellow on account of its superior luminosity; but if this luminosity be reduced to that of the red and green they will be compelled to judge of the result by the colour. This is at once called a reddish green, or a greenish red, according to the apparent predominance of one of these colours. If the colour correspond exactly to the modified unit red-green, the three-unit will not be able to distinguish which colour predominates, and are therefore very likely to call a reddish light, green, or a greenish light, red. The mistakes made are very much increased by shortening of the red end of the spectrum. Shortening of the red end of the spectrum, when met with in cases of the four, five, or six-unit, is not likely to cause confusion of red and green. It could only cause a red to be mistaken for a green under certain circumstances. The most penetrating rays of the spectrum are those on the extreme left, at the commencement of the red; therefore, if we had a colour which was red by virtue of these rays, but reflected a certain

number of green rays, it would appear green to a person with a spectrum shortened at the red end because the red rays would not be perceived. This is the actual constitution of many red lights when seen at a distance. Therefore there are persons who find to their surprise that though they can distinguish a red from a green easily enough when close to the colours, at a distance they either do not see the red at all, or it has changed to a green. On walking towards the red they find that it suddenly springs into view through the orange and red rays, which had previously been obstructed, reaching the eye. The reason why the red is not mistaken for the green when the observer is close to the colours, is that there are few, if any, coloured substances which reflect only the green and the extreme red. Nearly all red substances reflect the orange and the other red rays in such predominance as to cause the colour to be perceived as red, even if a portion of the red rays, which are reflected, be deducted from the total composition of the colour.

2. *Confusion of Green and Brown.*—This mistake is practically diagnostic of the three-unit at least. The three-unit regard brown (which is a deep shade of yellow) as a reddish green or greenish red, according to the portion of the spectrum to which the brown corresponds. A large number of browns which present no trace of green to the normal-sighted are called greens by the three-unit. Under the name of brown many colours are classed by the normal-sighted. Thus there are orange-browns, red-browns, yellow-browns, and purple-browns. The four unit can always distinguish the yellow-brown, which is a deep shade of yellow, from green; but this is the colour which presents especial difficulty to the three-unit.

3. *Confusion of Blue and Green.*—This is the diagnostic sign of the four-unit; a Cambridge blue, such as 40 and

45 of the Pocket Test, being the colour which is especially confused with green. An ordinary two-unit does not mistake this colour for green, but clearly distinguishes between the two. A two-unit, however, with a neutral band will, if the neutral band extend over this portion of the blue, confuse blue and green. For an instance of this see the case of Mr. Rix. The five-unit and the three-unit find a certain difficulty with blue and green, but not in the very marked degree that the four-unit do. It will be noticed that the blue is called green, and not the green blue, in accordance with the fact that the green has encroached upon the blue and not the blue upon the green. In the Board of Trade Report on Colour Tests for 1889, pale blue was called green in 249 cases, but pale green was called blue in only 6 cases.

4. *Confusion of Colours other than those mentioned above.*—The mistakes which I have mentioned above are those with which we most commonly meet. An epitome of the mistakes made by each class of the colour-blind will be found at the end of the chapter on the "Classification of the Colour-blind," to which I will refer the reader, as these mistakes are not diagnostic in character, and therefore do not call for special comment.

CHAPTER XVI.

PREVALENCE OF COLOUR-BLINDNESS.

At present it is not possible to say accurately to what extent the various degrees of colour-blindness exist, for the reason that nearly all the examinations have been made with Holmgren's test; and I have shown in other chapters that a red-green blind may only make such mistakes as would class him with those who have defective chromatic perception. Again, the four-unit colour-blind may make mistakes which would class them with the completely colour-blind. Again, there are many colour-blind persons who would escape detection by Holmgren's test. The percentage of colour-blindness by this method is about 4 per cent. The methods pursued by Dr. Wilson give more accurate results. He gives the percentage of colour-blindness at about 5½ per cent. He divides the colour-blind into the following classes—those who confound blue with green; those who confound brown with green; and those who confound red with green. The following is the percentage he obtained from the examination of 1154 persons. Those who confound blue with green, 2·2 per cent., or 1 in 46; those who confound brown with green, 1·6 per cent., or 1 in 60; those who confound red with green, 1·8 per cent., or 1 in 55. This gives a percentage of the colour-blind, including all classes of 5·6 per cent., or 1 in 17·7.

From the examinations which I have made, I have obtained very similar results; the percentage of the two-unit being about 2; the percentage of the three-unit being about 1·5; and the percentage of the four-unit being about 3. As the five-unit and the four-unit are, for all practical purposes, normal-sighted, they need not be included in the percentage. This makes the percentage of the colour-blind about 3·5 per cent., and this is near enough for all practical purposes.

About one-fifth of the educated male persons whom I have examined have had diminished colour-perception. The large majority of them belong to the class of the five-unit, and it is hardly fair to class them with the colour-blind at all. Women have a very much better colour-perception than men. For instance, in testing thirty ladies I only found one with diminished colour-perception. This lady belonged to the class of the five-unit. By the ordinarily used tests about one woman in two thousand is found to be colour-blind.

Colour-blindness, in my experience, is rather more common in the uneducated than the educated. With one exception, I have not found any particular class of individuals in whom colour-blindness is more frequent than in other classes. The one exception to which I refer is the class of musicians. I have found more colour-blind persons amongst musicians than in any other class or profession.

CHAPTER XVII.

ACCIDENTS WHICH HAVE OCCURRED THROUGH COLOUR-BLINDNESS.

There are many difficulties in the way of finding out the number of accidents which have occurred through colour-blindness. The chief of these difficulties appears to be the absence of any investigation as to the colour-perception of the navigating officers in cases of accident, and the very imperfect character of the tests in use. I am cognizant of several colour-blind pilots and officers in employment at the present time. These men are aware of the great difficulty which they experience in telling a red from a green light, and have consulted specialists with a view to having this defect remedied.

I have, therefore, looked up the records of a good many accidents, and will describe some showing how easily the accident might be explained by colour-blindness, and how inexplicable it is in any other way. Besides these, there are many accidents in which the cause has been definitely proved to be colour-blindness.

The Arlesey railway accident, which occurred on a Saturday afternoon, December 23, 1876, is easily explained by assuming that the engine-driver was colour-blind.

The *Times* says,* "An accident, almost as fatal in its result as that of Abbot's Ripton on the same line in the

* December 25, 1876.

early part of this year, occurred at the Arlesey siding station, four miles north of Hitchin, on the Great Northern Railway, on Saturday afternoon, at a quarter to four o'clock. Five deaths have already occurred, and about thirty persons are seriously injured. A luggage train was being shunted across the down line, when two of the trucks left the metals and thus delayed it in getting clear. Just at this time an express came up at full speed, and, although the signals were against it, the speed was not much diminished before the engine dashed into the luggage train, cutting its way completely through, and became imbedded in ballast some distance further on. Both the home and distant signals were at 'danger.' The down distant signal was eight hundred yards from the station. It was a little foggy at the time, and after the accident it came on to snow."

In this accident the reader will see that the condition of atmosphere was such that a red-green blind was particularly liable to mistake red for green, and *vice versâ*. Some one, writing to the *Times* at this time, objected to the theory of colour-blindness, as he said that he had often travelled with this driver, and he was sure that the latter was not colour-blind. Also the driver had been in the service of the company for a good many years. To those who are acquainted with colour-blindness, this is no argument. For instance, I see, by the last Parliamentary Report of the Board of Trade on colour-blindness, that men who had served twenty-nine, thirty, and thirty-five years at sea respectively, failed to distinguish a green from a red light.

The case of the collision of the steamship *Isaac Bell* and the tugboat *Lumberman* has been frequently quoted. The collision occurred near Norfolk, Virginia, and resulted in the loss of ten lives. The cause of the collision was

supposed to be drunkenness in one of the pilots, but there was no proof of this. The pilot of the *Lumberman* was afterwards examined, and found to be colour-blind; and there was a rumour that the pilot of the *Isaac Bell* was also colour-blind.

The following is a record of an accident occurring through colour-blindness. Mr. Haynes Walton, in a letter published in the *Times*, January 3, 1877, says, with regard to acquired colour-blindness,—

"A few years ago I was investigating colour-appreciation, and the first instance of the acquired defect that came to my knowledge was in the person of an engine-driver. This man confessed, after an accident through his not distinguishing the red signal, that he had gradually lost his colour-power, which had been perfect; and so sensible was he of his loss and its disadvantages, that before the accident he had determined to give up the situation."

The following case is related by Dr. Armstrong.* He says:—

"The master and owner of a steamboat on the Mississippi River brought a man to me for examination for colour-sense. The man proved to be colour-blind, and, on looking over the records, his rejection several years previous was found; the man said he had not expected to pass, and stated that his steamboat had once collided with and sunk a steamboat on account of his inability to distinguish the signal lights. His would-be employer was aware of these facts."

The following case is quoted by Mr. Bickerton. It is taken from the *Shipping and Mercantile Gazette and Lloyds' List*, dated June 29, 1881. The paragraph runs thus:—

"COLOUR-BLINDNESS, NEW YORK, JUNE 18TH.—The

* *British Medical Journal*, Jan. 28, 1888, p. 188.

pilot of the steamer *City of Austria*, which was lost in the harbour of Fernandia, Florida, last April, is proved to be colour-blind. In this it would appear that he mistook the buoys, and his mistake cost the owners 200,000 dollars (£40,000). An examination showed that at a distance of more than six feet, he could not distinguish one colour from another. The physicians attribute the defect to an excessive use of tobacco. The services of the Marine Hospital surgeons were tendered to the local authorities without fee two years ago, but were declined."

The following is related by Dr. Joy Jeffries:—

"Dr. Gintl, chief inspector of one of the Austrian roads, got the report of an accident due to colour-blindness, on the Finnish Road between Helsingfors and Tavastchus, in July, 1876. It was caused by a colour-blind switch-tender showing a green instead of a red light to the approaching train."

The following two cases are very interesting. The first is recorded in *Invention*, Dec. 28, 1889, and is an extract from a letter by "Thirty Years Railway Man." The second occurs in a letter by Mr. Stretton, published in the *Engineer*, Dec. 6, 1889.

i. "I have been on the railway for thirty years, and I can tell you the card tests and the wools are not a bit of good. Why, sir, I had a mate that passed them all, but we had a pitch into another train over it. He couldn't tell a red from a green light at night in a bit of a fog."

ii. "Some years ago a collision occurred on a railway in consequence of a train over-running a signal; the driver was firm in his statement that the light was 'green,' whereas all the other men said it was 'red.' The driver was fined, and afterwards continued at work as usual. He then made some other mistakes, which would

have ended in collisions had not the fireman said 'Stop mate.'

"Without any cause being stated, the driver decided to give up railway work, and take to another occupation. He some time afterwards informed me that he found that, when he had been on duty for seventeen hours, and especially in some states of the weather, 'he was not certain about red and green,' and he believed that his sight was the cause of the collision. Now, as a fact, that man could then, and can now, pass the 'dot' and 'wool' tests without any trouble. In all cases in which collisions occur in consequence of mistakes of signals, it would be a great advantage if the Board of Trade inspectors would have the men's sight tested before they come to the conclusion that one or other man is not speaking the truth."

If it had not been for the railway men themselves, I should not have been able to give the above two instances of collisions occurring through colour-blindness. In both cases, the fact that the men were colour-blind appears to have escaped the attention of the authorities. It is a great pity that, when men differ in their statements as to the colour of a light, they are not examined by an expert and their colour-perception definitely ascertained. It is absurd for persons who are unacquainted with the subject to say, over and over again, "Bring forward evidence that colour-blindness has caused accidents on railways;" because how can we bring forward evidence when the men are not tested? Hundreds of accidents may be caused by colour-blindness, and in all probability are; but how can we tell whether this is the case, if the men are not examined? To show how difficult it is to get the authorities to recognize the importance of this subject, I may mention that I received a letter from

a colour-blind medical man, telling me that some years ago he had written to one of the assessors in a collision at sea. I will give an extract from his letter. The observations are those of an accurate observer.

"I cannot distinguish a ship's *green* light beyond about five hundred yards. I found this out accidentally some years ago, when watching the arrival of a P. and O. steamer at Venice. At a certain point, rather more than a mile off, she "opened," as the phrase is, her green light; to me it appeared white, and remained so until, having passed me at about five hundred yards, I saw no more of it. I then turned attention to some small steamers following the same course, but which turned to the right, and came in to where I was standing. I found that the green light, which I saw quite white, became first a very pale blue, and then a little darker blue; and then, when about three hundred or four hundred yards, perhaps less, I recognized the green. It may be assumed that all the lights of the P. and O. ships are of the best quality. The green light which I saw as white was quite as bright to me as the masthead light. The same may be said of the lights of the other steamers mentioned. From inquiries among sailors, I am pretty sure that there are some—a small percentage, perhaps—who are similarly circumstanced. I have been told also that the non-recognition of a green light could not lead to any disaster by collision, as sailing vessels carry no masthead lights, and so no mistake should occur. But some ports, at least, in the Mediterranean, have red and green lights, and so it might be of consequence that the green light should be seen as such. Having read of a running-down case some time ago, which came to trial, I wrote to one of the assessors (an admiral), telling him of my case. In his answer he stated that in such cases his experience was—that there was always a

great deal of hard swearing. If I recollect rightly, the look-out swore that he only saw a white light. I think that the collision was between two sailing vessels."

From this it will be seen that if every case in which one man swears that he saw a light of one colour, and others swear that they saw a light of another colour, is put down as a case of hard swearing, we shall not be able to prove that many collisions are due to colour-blindness.

The remedy in these cases is so simple. Have the man tested to see whether he be colour-blind or not. If the word "colour-blindness" were substituted for hard swearing in the admiral's letter, I think that we should be nearer the truth. It is evident, from the assessor's reply, that there are great differences of opinion in these cases with regard to the colour of the light seen. In my opinion the case should not be put down as one of hard swearing until the witnesses have been proved to be normal-sighted.

The two following cases have been recorded by Mr. Bickerton.* He says:—

"The following account is written by Captain Coburn, who was for many years in the employ of Messrs. Leach, Harrison, and Forwood, of Liverpool, and is to be found in the *Mercantile Marine Reporter*, vol. xiv., No. 162: 'The steamer *Neera* was on a voyage from Liverpool to Alexandria. One night, shortly after passing Gibraltar, at about 10.30 p.m., I went on the Bridge, which was then in charge of the third officer, a man of about forty-five years of age, and who, up to that time, I had supposed to be a trustworthy officer, and competent in every way. I walked up and down the bridge until about 11 p.m., when the third officer and I almost simultaneously saw a light

* *British Medical Journal*, March 8, 1890, p. 539.

about two points on the starboard bow. I at once saw it was a green light, and knew that no action was called for. To my surprise the third officer called out to the man at the wheel, "Port," which he was about to do, when I countermanded the order, and told him to steady his helm, which he did, and we passed the other steamer safely about half a mile apart. I at once asked the third officer why he had ported his helm to a green light on the starboard bow; but he insisted it was a red light which he had first seen. I tried him repeatedly after this, and although he sometimes gave a correct description of the colour of the light, he was as often incorrect, and it was evidently all guesswork. On my return I applied to have him removed from the ship, as he was, in my opinion, quite unfit to have charge of the deck at night, and this application was granted. After this occurrence I always, when taking a strange officer to sea, remained on the bridge with him at night until I had tested his ability to distinguish colours. I cannot imagine anything more dangerous or more likely to lead to fatal accidents than a colour-blind man on a steamer's bridge.'

"A similar experience is thus related by Captain Heasley, of Liverpool: 'After passing through the straits of Gibraltar, the second officer, who had charge of the deck, gave the order to port—much to my astonishment, for the lights to be seen about a point on the starboard bow were a masthead and green light; but he maintained that it was a masthead and red, and not until both ships were nearly abreast would he acknowledge his mistake. I may add that during the rest of the voyage I never saw him making the same mistake. As a practical seaman I consider a great many accidents at sea arise from colour-blindness.'"

Accidents did not occur, because the erroneous inter-

pretation of the light was corrected in each case by a normal-sighted person. Accidents probably would have occurred if the boats had been solely under the direction of the colour-blind officers.

CHAPTER XVIII.

COLOUR-BLINDNESS IN THE NAVY, MERCANTILE MARINE AND PILOT SERVICES.

THIS and the following chapter I have written in order to show the necessity of preventing colour-blind persons from acting in capacities for which they are physically unsuited. It is necessary to give details to show the limit of exclusion in the classes of the colour-blind.

If we could find signals which would be easily distinguished by colour-blind persons as well as by the normal-sighted, there would be no reason for excluding them at all. But this is not possible. Let us, for example, take a two-unit colour-blind. The only colours that are distinguished with certainty by him are yellow and blue-violet. Even supposing that it were possible to manage with only two signals, these colours would be the worst to use for signalling purposes. If used, we should not get over the difficulty, for the following reasons. Gas and lamplight are very deficient in the blue rays, and therefore a light of this colour would appear very feeble, and only visible at a short distance. Besides, I have not been able to find a blue or violet glass which is impermeable to the red rays. It would be necessary to have a glass of this description, because the deficiency in the blue rays would throw the colour towards the red unit. When the red rays preponderated the colour would be perceived as red,

and mistaken by the two-unit for the yellow. In addition to this the yellow and blue rays are less penetrating than the red and green and, therefore would only be visible at a shorter distance.

A white (yellow) light is the one which can be seen at the greatest possible distance, for the obvious reason that nearly all the rays are transmitted through the glass. A coloured light is always obtained by subtraction from the number of rays transmitted, and therefore must have less illuminating power than the original light. Of all colours red is that which can be seen at the greatest distance, because the red rays of the spectrum are the most penetrating. Red is, therefore, the colour which should be used for a danger-signal, and the glass used should be perfectly transparent to the red rays. It is not of so much consequence that the other rays of the spectrum be perfectly excluded, because, if the light be red at first, and the glass be perfectly transparent to the red rays, the light will remain red under all ordinary atmospheric conditions.

Red and green are the best colours which could be chosen. The glasses of these colours form the greatest contrast to each other, as each is opaque to the rays to which the other is transparent. The ordinary ruby glass is transparent to the red and orange rays of the spectrum, and completely opaque to the yellow, green, blue, and violet. The standard blue-green glass is practically opaque to the red, orange, and yellow, and transparent to the green, blue, and violet. It will be seen that both glasses are opaque to the yellow rays. If a third light be used, yellow is the best colour. As should be the case, the red is the light which is visible at the greatest distance. Next to the red rays the yellow-green rays are the most penetrating, and therefore it is important that the green glass should be

perfectly transparent to these rays. Though it is of no importance whether the green glass is transparent to the yellow rays or not, it is of the greatest importance that no red rays pass through the glass. If any red rays pass through, in addition to impairing the colour, these rays may be a direct source of error in case of a fog. In a fog the whole of the rays may be obstructed with the exception of the red, and so the light may appear as a very much impaired red. It is probably for this reason that blue-green is used instead of green; but the standard blue-green of Trinity House is not completely opaque to the red rays. A very bright green, completely opaque to the red rays, can easily be obtained, and this should be used. Under no circumstances could a normal-sighted person mistake this green for red.

From this it will be seen that the best colours we can use are red, from a glass allowing only the red and orange to pass through; and green, from a glass allowing the violet, blue, green, and yellow to pass through, and being perfectly transparent to the yellow half of the green, and opaque to the orange and red rays.

The following regulations of the Board of Trade for preventing collisions at sea, especially bear on the subject of colour-blindness and defects of sight in seamen:

Rules concerning Lights.

Art. 3. A seagoing steamship when under way shall carry—

(*a.*) On or in front of the foremast, at a height above the hull of not less than twenty feet, and if the breadth of the ship exceeds twenty feet then at a height above the hull not less than such breadth, a bright white light, so constructed as to show an uniform and unbroken light over an

arc of the horizon of twenty points of the compass, so fixed as to throw the light ten points on each side of the ship, viz., from right ahead to two points abaft the beam on either side, and of such a character as to be visible on a dark night, with a clear atmosphere, at a distance of at least five miles.

(*b*.) On the starboard side, a green light so constructed as to show an uniform and unbroken light over an arc of the horizon of ten points of the compass, so fixed as to throw the light from right ahead to two points abaft the beam on the starboard side, and of such a character as to be visible on a dark night, with a clear atmosphere, at a distance of at least two miles.

(*c*.) On the port side, a red light, so constructed as to show an uniform and unbroken light over an arc of the horizon of ten points of the compass, so fixed as to throw the light from right ahead to two points abaft the beam on the port side, and of such a character as to be visible on a dark night, with a clear atmosphere, at a distance of at least two miles.

(*d*.) The said green and red side lights shall be fitted with inboard screens projecting at least three feet forward from the light, so as to prevent these lights from being seen across the bow.

Art. 6.—A sailing ship under way, or being towed shall carry the same lights as are provided by Article 3 for a steamship under way, with the exception of the white light, which she shall never carry.

From the above it will be seen that it is necessary for a look-out man to be able to distinguish between the red

and green lights at a distance of two miles. It is therefore essential that he should be able to recognize both coloured lights at this distance. He should be able to see the white light of a steamer at a distance of five miles.

It will be seen that individuals included in the following three classes should be excluded from positions in the navy in which they are required to distinguish between the red, green, and white (yellow) lights.

I. Those who possess a psycho-physical colour-perception with three or less units.

II. Those who, whilst being able to perceive a greater number of units than three, have the red end of the spectrum shortened to a degree incompatible with their recognition of a red light at a distance of two miles.

III. Those who are affected with central scotoma for red or green.

Details of the reasons for the exclusion of the above three classes are given in the chapter on the Tests for Colour-Blindness.

In May, 1877, the Board of Trade instituted an examination in colours for those seeking certificates of competency as masters or mates. In 1887 the method was slightly improved, and has not been altered up to the present time.

The following circular, issued by the Board of Trade to their examiners, will show the method adopted.

Instructions to Examiners.

Examination in Colours.

Herewith are—

(*a.*) A lanthorn having in it a lamp in which kerosine is to be burnt.

(*b.*) A slide having ground glass in it.

(*c.*) Nine slides, each having a coloured glass in it. The colours are as follows:—

1. Red (Standard).
2. Pink or salmon.
3. Green (Standard or No. 1).
4. Green (Bottle or No. 2).
5. Green * (Pale or No. 3).
6. Yellow.
7. Neutral.*
8. Blue (Standard).
9. Blue * (Pale).

(*d.*) Cards, five of each as follow:—

1. White.
2. Black.
3. Red.
4. Pink.*
5. Green.
6. Drab.*
7. Blue.
8. Yellow.

Examination by Daylight (Cards.)

In conducting the examination by daylight the examiner should do it in three ways.

1. The cards should be mixed up. The examiner should then hold up each card separately and ask the candidate to name the colour, and if the candidate does so without hesitation he is to be regarded as having passed the daylight test.
2. If the candidate hesitates in any of his answers so as to raise a doubt in the mind of the examiner as to his ability to readily distinguish colours, the examiner should put all the cards on the table and require the candidate to select all cards of a colour or colours named by the examiner.
3. Having done that, they should all be mixed up again, and the candidate should be required to sort the cards into eight heaps, putting all of one colour into each heap.
4. The result of the examination should be noted and recorded in each case.

Examination by Artificial Light.

The room should be dark.

The lamp lighted and placed in the lanthorn.

The applicant should be seated or should stand so as to be opposite to the opening of the lanthorn; and, at least, fifteen feet from the front of the lanthorn.

He should first of all see the light in the lanthorn without the interposition of any glass, and be asked if it appears to him to have any colour, and, if so, what colour?

The slide with the ground glass should then be put into the opening at the front of the lanthorn which is nearest to the light, and the applicant asked the same question.

The slide with the ground glass is to be left in, and the slides with the coloured glasses placed one by one and separately in front of it, and the candidate asked in each case to name the colour or tint.

The result of the examination should, of course, be noted and recorded in each case.

General.

The cards and glasses against which a star * is placed in the list are what may be called confusion tints. The candidate is not to be regarded as having "failed" if he miscalls these tints, provided that he names all the others correctly. But if having named all the others correctly he miscalls these so far as to name the drab card No. 6 as red, pink, salmon, etc.; or to name card No. 7 as red, green, or yellow; or glass No. 2 as green, blue, or yellow; or glass No. 5 as red, pink, salmon, etc.; or glass No. 7 as bright red or bright green; or the plain ground glass any colour, the case should be reported for record. In short, if the candidate's perception or impression of these tints does not agree with the perception of the examiner, the case should be reported on the Form Exn. 17B.

The only reasons for which a candidate is to be reported as having failed are inability to distinguish red from green, or either from black, by daylight; and red from green, or either from the ground glass, by artificial light.

If a candidate fails in the colour-test when the ground glass is in the lanthorn (as it is always to be when the coloured glasses are shown), he may also be tried over again with the coloured glasses without the intervention of the ground glass, and the result noted and recorded.

The following are the regulations under which candidates are admitted for examination :—

Circular.

COLOUR TESTS.

The Board of Trade have made the following arrangements for the examination of persons as to their ability to distinguish colours :—

1. Examinations in colour are open to any person serving or about to serve in the Mercantile Marine.

2. Any person, including the holders of certificates of competency, or persons about to apply for certificates of competency, if desirous of being examined *in colours only*, must make application to a Superintendent of a Mercantile Marine Office on Form Exn. 2a, and pay a fee of one shilling.

3. He must, on the appointed day, attend for examination at the examiner's office; and if he passes he will receive a certificate to that effect.

4. If he fails, it will be open to him to be examined again in colours as often as he pleases, on payment of the fee of one shilling at each fresh attempt.

5. The application of a *candidate who is presenting*

himself for examination for a master's or mate's certificate must be made on Form Exn. 2. Such examination will commence with the colour-test; and if the candidate does not at the time of making application hold a certificate of competency of any grade, and should fail to distinguish correctly any one of the colours used in the test, he will not be allowed to proceed with the examination in navigation and seamanship.

6. The fee he has paid for examination for a certificate of competency will include the fee for the colour-test, and, with the exception of one shilling, will, in such event, be returned to him.

7. A candidate for examination for a certificate of competency who at the time of making application does not possess a certificate and who fails to pass the colour-test, may not be re-examined until after the lapse of three months from the date of his first failure. If he fail a second time, he will be allowed a third trial at the expiration of another three months from the date of his second failure. A fresh fee must be paid at each succeeding examination.

8. It is therefore obviously to the advantage of candidates for certificates of competency, to apply in the first instance to be examined in *colours only*, on Form 2a.

9. A candidate who holds a certificate of competency, and who, on presenting himself for examination for a certificate of a higher grade, is unable to pass the colour-test, will notwithstanding be permitted to proceed with the examination in navigation and seamanship for the certificate of the higher grade.

10. Should he pass this examination, the following statement will be written on the face of the higher certificate which may be granted to him, viz., "This officer has failed to pass the examination in colours."

11. Should he fail to pass the examination in navigation and seamanship, a like statement, relating to his being colour-blind, will be made on his inferior certificate before it is returned to him.

12. Holders of certificates which bear the statement of their having failed to pass in colours, and who may desire to have the statement removed from their certificates, must obtain the special permission of the Board of Trade."

The following three tables show the results of the examinations for the last twelve years, from 1877 to 1889:—

COMPARATIVE TABLE.

Showing the Number and Percentage of Rejections for Imperfect Colour Sense during the Twelve Years from 1877 to 1889.

Years.	I. Form Exn. 2.			II. Form Exn. 2a.		
	Number examined.	Number rejected for Imperfect Colour Sense.	Per centage so rejected.	Number examined.	Number rejected.	Per centage rejected.
1877–79 (Two years)	5,967	26	·43	—	—	—
1879–80	4,334	16	·37	10	—	—
1880–81	4,319	16	·37	182	5	2·75
1881–82	4,079	19	·46	59	8	13·56
1882–83	4,009	26	·65	69	6	8·7
1883–84	4,603	17	·37	56	10	17·86
1884–85	4,350	23	·52	110	8	7·27
1885–86	4,215	45	1·06	294	18	6·12
1886–87	4,124	25	·61	415	26	6·27
1887–88	4,128	17	·41	837	33	3·94
1888–89	4,443	18	·40	789	36	4·56
Totals and general averages	48,571	248	·51	2821	150	5·31

SUMMARY.

Showing the Number and Nature of the Mistakes made by the Rejected Candidates named in the Foregoing List.

Colours of Cards.	White.	Black.	Red.	Pink.	Green.	Drab.	Blue.	Yellow.	Other Colours.
White described as ...	—	—	—	1	1	—	—	—	—
*Black ,, ...	—	—	17	—	14	—	5	—	8
*Red ,, ...	—	—	—	4	32	2	—	1	—
Pink ,, ...	5	—	39	—	124	4	34	4	16
*Green ,, ...	4	—	6	16	—	45	8	13	12
Drab ,, ...	6	—	5	21	203	—	—	2	31
Blue ,, ...	—	—	—	1	11	4	—	—	1
Yellow ,, ...	8	—	—	—	11	—	—	—	1

Colours of Glasses.	Ground.	Red.	Pink.	Green.	Pale Green.	Yellow.	Neutral.	Blue.	Pale Blue.	White.	Other Colours.
*Ground described as	—	6	3	11	1	5	—	2	—	117	12
*Standard Red ,,	—	—	—	15	—	14	—	3	—	1	9
Pink ,,	—	139	—	93	—	144	—	3	—	16	46
*Standard Green ,,	—	83	23	—	2	13	47	47	1	16	11
Bottle ,, ,,	—	303	14	—	—	9	1	14	—	4	16
Pale ,, ,,	—	120	6	—	—	71	4	6	—	63	21
Yellow ,,	—	234	2	34	—	—	2	2	—	24	40
Neutral ,,	—	74	8	214	—	21	—	19	1	39	27
Blue ,,	—	10	4	109	—	—	—	—	—	1	16
Pale Blue ,,	—	8	16	249	41	—	1	—	—	23	24
White ,,	—	—	—	—	—	—	—	—	—	—	—

The first half of the Comparative Table relates to examinations held under Form Exn. 2, *i.e.*, as a necessary part of the general examination for a certificate as master or mate. The second half relates to examinations held under Form Exn. 2a, *i.e.*, in colours only, without reference to further capacity. The tests used are the same in each case; but

* Colours for failure in distinguishing which the Board of Trade reject candidates.

whereas for Examination 2 all the candidates are intending officers, among those who are examined under the other scheme is a large number of seafaring persons who do not intend to become officers, but are, for some reason, desirous of testing their capacity to distinguish colours.

With regard to the Royal Navy, the following extract * from the "Queen's Regulations and Admiralty Instructions" regarding the examination of candidates for admission into the Naval Service or into the Royal Marines, as regards colour-sight, will show how insufficient are the means adopted.

"Whenever test-types are supplied, the power of vision of each eye separately, as well as together, is to be ascertained. If the persons under examination fail to distinguish the colours [of the coloured test-types] they should be tried with brighter and decided colours; for this purpose, red, blue, green, and yellow ribbon flags may be used."

The Admiralty also use coloured wools for doubtful cases among officers.

It seems incredible that, with our present knowledge of colour-blindness, the above should be considered an efficient test for this defect. I can hardly conceive anything more inefficient and calculated to allow colour-blind persons to escape detection. It seems to me the only effect of these tests is to make colour-blind persons more dangerous than before, because if they had any doubts as to their power of seeing colours properly, these would be allayed by having passed a test. The following will show how useless these so-called tests are in practice.

A friend of mine, who wished to enter the Royal Navy, came to me, and said, "I feel very doubtful as to my power of seeing colours; I wish you would examine me."

* "Optical Manual," by Sir T. Longmore, p. 151.

I did so, and found him colour-blind in a marked degree. He belonged to the class of the two-unit. His spectrum was not shortened at either end, but there was a large neutral band between the two colours. This neutral band extended on the red side to about the middle of the green, to a point midway between E and F. The colour on the red side of the neutral band he called "red," that on the violet side "blue." He made mistakes in accordance with the above examination with the spectrum. He said, "I think there is something wrong with my colour-perception, as there appears to me to be very little difference between many colours which have different names; but, of course I know the ordinary colours, for instance,"—pulling out a pair of yellow-brown gloves,—"these gloves are a decided red." He then asked me if I thought that he would be able to get through the colour-test. I told him that he had better give up the idea of entering the navy, as he was one of the worst cases of colour-blindness I had come across. I told him that many dangerously colour-blind could get through the tests in use at the present time, but that his colour-perception was so very defective that I could hardly think it possible that he could get through the most inefficient test.

A few weeks afterwards I saw him again. He at once came up to me, and said, "Well, I got through." I then inquired what the test was, and how he had managed to get through it. He said that he was examined with little coloured flags. Having been shown a flag he was asked the name of the colour. He said, "I had no idea what the colour was, but answered very decidedly, 'Red.' The examiner said, 'Quite right,' and showed me another flag. This I knew by its brightness to be yellow, but determined to take advantage of this knowledge, and answered, 'Old gold.'" He was then shown a flag very similar (to him)

in colour to the first one. Concluding that he would not be shown the same again, he answered "Green" correctly. He was then shown the blue flag, which he did not find much difficulty in recognizing.

I hope that the above remarks will lead the authorities to adopt more efficient tests. A test like the above does more harm than good, as it gives a sense of false security.

The Pilot Service is independent of the Board of Trade and Admiralty, some of the pilots being under the control of the London Trinity House, and others under the independent Pilotage Boards of the principal ports, of which there are eighteen.

At the end of 1884 the Board of Trade issued a circular letter to the various pilotage authorities of the United Kingdom, inquiring whether any and what test of their ability to distinguish primary colours was applied to the pilots under their jurisdiction.

In answer to these letters the Board of Trade were informed that the Tees Pilotage Commissioners; Trinity House, Newcastle-on-Tyne; Dundee Pilotage Committee; Gloucester Pilotage Commissioners; Hartlepool Pilotage Commissioners; Bristol Docks Committee; Tyne Pilotage Commissioners; Newport Pilotage Board; Swansea Harbour Trust; Chester Pilotage Trustees; and Aberdeen Harbour Commissioners applied no test for colour-blindness. The Clyde Pilot Board; Dublin Port and Docks Board; Mersey Docks and Harbour Board; Trinity House, Hull; and Trinity House, London, had instituted a test for colour-blindness, but had had no failures. The Sunderland Pilotage Commissioners and Trinity House, Leith, had instituted a test for colour-blindness—result not stated. The Cardiff Pilotage Board did not examine a person unless he produced a Board of Trade certificate as to colour-blindness.

In order to find out if any alteration had been made since the Board of Trade inquiry, I wrote to each of the Pilotage Boards, asking if any and what tests were used. I received answers from eighteen out of the nineteen Pilotage Boards.

The Swansea Harbour Trust; Chester Pilotage Trustees; Newport Pilotage Board and Aberdeen Harbour Commissioners use no test for colour-blindness. The Sunderland Pilotage Commissioners; Cardiff Pilotage Board; Gloucester Pilotage Commissioners; Bristol Docks Committee; Trinity House, Newcastle-on-Tyne; Dublin Port and Docks Board; Trinity House, Leith; Trinity House, Hull; Hartlepool Pilotage Commissioners; Tyne Pilotage Commissioners and Dundee Pilotage Committee use the Board of Trade tests. The Clyde Pilot Board have their pilots examined by a specialist who uses various methods. The Mersey Docks and Harbour Board and Trinity House, London, test their pilots with coloured glasses.

It will be seen that the condition of things is very unsatisfactory. There are many pilotage authorities who do not consider it necessary to test for colour-blindness at all. The multiplication of examiners, and, in most cases, the absence of special training, all tend to make the testing unsatisfactory in the extreme.

When I consider the life and property depending upon a correct recognition of the coloured lights, it seems to me incredible that more attention is not paid to the subject of colour-blindness.

In order to find out whether the steamship companies use any extra tests for colour-blindness, I wrote to the chief of them, inquiring whether this was the case.

The Cunard Steamship Company replied as follows:—

"The surgeons of our vessels examine all our look-

outs for colour-blindness and for long and short sight, as also for hearing, using in the first process different coloured glasses, worsteds, etc. Our officers, however, are periodically examined by a competent medical officer on shore, who is left to the exercise of his own judgment in the method of so doing."

The Peninsular and Oriental Steamship Company test their officers with coloured wools, but do not test their look-outs.

All the other companies to whom I wrote did not employ any additional tests.

When I was surgeon in the Peninsular and Oriental Company's service, I removed a man who was nearly blind from acting as look-out. This man could not say whether one finger or five were held up before him. I must mention that the officers of the ship were not aware of the condition of the man's sight, or he would not have been allowed to act as look-out. The captain of the ship was the most thorough and careful sailor I have met—a man who acted up to the letter and spirit of his duties in a way which could not be surpassed. I mention this just to show that, even with an exceptionally able captain, there may be incompetent look-outs, unless the latter have been properly tested.

Shipowners and the Directors of Shipping Companies will not recognize the importance of having normal-sighted officers and look-outs. The views of a large number are similar to those of a shipowner, who, on being told of the dangers of colour-blindness, remarked, "I do not see the importance of not having a colour-blind officer on a ship. *There are always several men about.*" The italics are mine.

CHAPTER XIX.

COLOUR-BLINDNESS IN RAILWAY EMPLOYÉS.

It is obvious from what I have already said, that persons belonging to classes of the colour-blind which it would be necessary to exclude from employment as sailors, would be equally dangerous if employed as engine-drivers. In addition to this, colours are used on railways which are not employed at sea, such as purple and blue.

In the early part of August, 1889, I issued a circular to the managers of the principal English railway companies requesting for information concerning the colours of the lights used on their railways. Most gave the information desired. My purpose in making the investigation was to find out at what class I should draw the line in excluding persons from being employed as engine-drivers.

The Midland; and London, Tilbury, and Southend Railway Companies use red for "danger," green for "caution," and white for "all right." The London and North Western use a red light for a "danger" signal, and a white light as an "all right" signal for intermediate block cabins and unimportant stations, and the green light as a "caution" signal for junctions and important stations. The following use red for "danger," and green for "all right"—Great Northern; Metropolitan; Eastern and Midlands; Metropolitan District; London, Brighton, and South

Coast; and East London. The Great Western Railway Company use red for "danger," and white for "all right."

The London, Tilbury, and Southend; and Eastern and Midlands Railway Companies, in common with many others, use a purple ground disc as a stop-signal for siding and shunting purposes only. The Great Northern Railway Company uses a tint of yellow-green instead of the blue-green, which is used by most companies. This they do on account of the fact that the light is reduced to a much greater extent in passing through a blue-green than in passing through a yellow-green glass. A purple light, when exhibited on a fixed post on the "slow" or "additional" lines is the "all right" signal for these lines.

It will therefore be seen that the lights used by the different railway companies are by no means uniform in colour and method. Whilst a red light is the universal "danger" signal, green is the "all right" signal on some lines, white on others. Again, some companies use all three signals, green being used as a "caution" signal. The tint of green also varies; for whilst the majority of the railway companies use a blue-green, the Great Northern Railway Company uses a yellow-green light.

A purple light is used by many companies as a "stop" signal for siding and shunting purposes; whilst the Great Northern uses a purple light as an "all right" signal for the "slow" or "additional lines."

The London, Brighton, and South Coast Company uses red as a "danger" signal, and blue-green as an "all right" signal throughout; the ground discs having similar lights to the semaphore signals.

As far as the signals go, the colours to be distinguished are, red, white (yellow), yellow-green, blue-green, and purple. A blue light is also used for the lamps of

trains, and therefore this colour must be added to the list of colours to be distinguished.

The remarks which I have made in the chapter on "Colour-blindness in the Navy," with regard to the coloured lights, are equally applicable to those on railways. Red and blue-green are the colours which are most easily distinguished from each other by normal-sighted persons. An ordinary red-green blind will distinguish a blue-green from a red light with greater ease than he will if the green be of a yellow tint. Unless the yellow-green glass be very carefully chosen, it may lead the normal-sighted into trouble. The reason why the Marine Department of the Board of Trade altered the hue of the green from a yellow to a blue-green was that the colour in a fog appeared very much like a dirty red. Many yellow-green glasses are transparent to many of the red rays, and these rays, with their superior penetrating power, will, in a fog, very considerably influence the colour of the light.

There seems to me no reason why the three lights, red, green, and white, should not be sufficient for all ordinary purposes. It does not seem to me that a "caution" signal is necessary, and that it would be better to have a positive "all right" signal, such as the green light. Then, if the glass of the red light were broken, there would be no danger of an accident occurring through it.

I do not think it is necessary to use a different coloured light for siding and shunting purposes. At any rate, a purple or blue light should never be used as an "all right" signal, because glasses of this colour are transparent to the red rays, and so the colour might easily be converted into red.

Having shown what colours it is necessary for the engine-driver to distinguish between, let us consider the

tests used by the different railway companies, and their efficiency for the purpose required. I am indebted for most of the information concerning these tests to the *Railway Press.* The editor of this paper issued a circular to the managers of the different railway companies, requesting for information concerning the methods employed in testing for colour-blindness. In the majority of instances a reply was sent, giving details of the tests used. The answers are published in full in the *Railway Press,* September and October, 1889, and are well worth perusal.

The North British Railway Company test with a board placed thirty feet distant, with seven coloured spots printed on it, viz., white, red, green, brown, blue, black, and yellow. The test is conducted personally by the locomotive superintendent. Every fireman, on being appointed, is tested for colour-vision, and again when he is appointed as a driver. No further tests are made unless some grounds arise for believing that a man's vision is impaired.

The Great Northern Railway Company test with skeins of coloured wool. The method is not described.

The Midland Railway Company test with a modification of Holmgren's wools. The examination is conducted by the company's clerks.

The North Eastern Railway Company test with skeins of coloured wool, and by such other tests as the company's surgeons think it desirable to make.

The London and North Western Railway Company test their men annually with a card on which four colours are printed, with a series of dots for testing the vision between each pair of colours. The upper pair of colours are red and green, the lower pair blue and yellow. The examination is made by the foreman of the different districts. If any of the men fail to pass, they are examined subsequently by the company's surgeon.

The London and South Western Railway Company test with coloured wools and lights as follows: "When examined with the lights, the men are tested in a dark room, and they have to name them correctly. With the wools, they have to pick out a certain number of skeins of the colours in varied shades, and name them correctly."

The South Eastern Railway Company test those applicants who do not intend to become engine-drivers, by requiring them to match colours from a collection of coloured objects or wools of various tints, and by "Snellen's Tests." "Applicants for employment as engine-drivers enter the service as engine-cleaners, and, as a preliminary, a collection of coloured wools is placed before the candidate, and he is requested to pick out various colours as directed; and, unless he is able to distinguish the colours readily, is not considered eligible. In time an engine-cleaner is promoted to fireman, and, on this taking place, the colour-test is again applied, supplemented with hand-flags at various distances.

The London, Brighton, and South Coast Railway Company appear to test by Holmgren's method.

The London, Chatham, and Dover Railway Company test with coloured lights in the following manner: A tube, twenty feet long, is used; at the end of which is a revolving disc, containing a series of coloured glasses. The colours are confined to the primary ones. The examiner can revolve the disc to any colour he likes, and asks the candidate the name of the colour. The candidate is also tested with a distant signal at eighty yards, which is under the control of the examiner.

The North London Railway Company test by cards, with coloured stripes and spots respectively.

I can hardly conceive anything more unsatisfactory than most of the above-mentioned tests. The test, for

instance, which consists of four colours painted on a board in definite positions. A normal-sighted person might tell a colour-blind person the names and positions of the four colours.

The following letter, which appeared in the *Railway Press*, Dec. 13, 1889, is a good example of the unsatisfactory state of affairs with regard to testing for colour-blindness by the railway companies.

"COLOUR-BLINDNESS.

"Sir,

"Having read in your valuable paper a very interesting account of how the different companies test their servants as to their eyesight, I will now give you my experience before I was made permanent on the London and North Western and Great Western joint companies, Birkenhead. After being in their employ a few days, I was sent with a medical examination form to the company's doctor, to be filled up by him. He examined me; also asked me a few questions as to health and age, which he put on the certificate as I answered them. Then came the test as to my eyesight. He handed me a small basket containing skeins of coloured wool. He took from the basket three small skeins of different colours, and told me I was to match them to the best of my belief with the others that were left in, at the same time telling me there was none there exactly the same colour as what he gave me. After a little patience I matched them, as I thought, as near as could be. After doing so, he filled up my certificate, signed it, also asked me to do the same. But to my surprise, when I took it to my inspector, he told me I was colour-blind, and that I could not be made permanent. I told him that I was sure that my eyesight was good. I again had to visit the

same doctor, and went through the same performance with the skeins of coloured wool as before, and again he put me down as colour-blind. I was sent to him by my inspector for the third and last time, and he still said I was colour-blind. After this I was sent to our superintendent's office at Shrewsbury, and went through a severe test before my superintendent. First, I was placed by the office-window, and two flags, red and green, were held up, quite a quarter of a mile away, which I distinguished quite easily. Then I was tested with papers of different colours, and lastly with a square board with a quantity of small dots on, similar to the one used by the London and North Western Railway Company, and was successful in answering all questions correctly. I was next sent to the company's doctor in Shrewsbury, and was examined by him the same as I had been by the doctor in Birkenhead. But instead of the basket of skeins of coloured wool, he held up three knots of wool, red, white, and green, and asked me the colour, which I named correctly. After all this testing I was made permanent; and I question whether any other railway servant went through so much testing as what I did. You will now see that extreme care should be taken to really find out who is really colour-blind. The old saying applies in this case that 'doctors differ,' and that it is necessary that more than one person should judge a matter of this kind.

"Yours, etc.,

"WILLIAM VAUGHAN, Signalman.

"Birkenhead, December 9, 1889."

Here a man was tested three times by one of the companies' surgeons, and found to be colour-blind each time. Still the superintendent is not satisfied, and himself tests the man, and then sends him to another of the

companies' surgeons. He is again tested, and the decision of the first surgeon reversed. From reading this letter, I am inclined to think that the writer was colour-blind. At any rate, neither the method of testing employed by the superintendent, nor that of the doctor at Shrewsbury, as described in this letter, is in any way an efficient test for colour-blindness. Why did not the companies have the man examined by an expert? This shows very well the way in which colour-blindness is regarded by the public. The three first examinations apparently counted for nothing. Had the superintendent appreciated the dangers of colour-blindness properly, he would have certainly referred to some expert before keeping the man.

CHAPTER XX.

THE TESTS FOR COLOUR-BLINDNESS.

Unfortunately nearly all the tests for colour-blindness in use at the present time have been based upon some theory of colour-perception. In this chapter I intend to deal with colour-blindness from a purely practical point of view. All the observations are based on the facts of colour-blindness, apart from any theory, and so will hold good whatever theory be adopted.

Tests for colour-blindness are of two kinds; namely, those which are used for the purpose of ascertaining whether colour-blindness be present or not, and those which are used when the inquiry is made for some practical purpose. In Chapter XI. I have dealt with the first division of tests for colour-blindness, and it now remains for me to deal with the second.

On account of the arrangement of signals by sea and land, it is necessary that persons employed in the marine and railway services should be able to recognize and distinguish between the standard red, green, and white lights under all conditions in which they are likely to be placed.

It is not only necessary to find out whether a person is able to distinguish between the red, green, and white lights, but to ascertain as well that he thoroughly understands what is meant by colour, and the individual

characteristics of red, green, and white, respectively. Too little attention has been paid to this in constructing tests for colour-blindness, and those who have had much practical experience in testing for this defect, are aware of the ignorance which exists among uneducated persons with regard to colours. Many are under the impression that every shade of a colour is a fresh colour, and others have the most novel ideas with respect to colour. It is necessary that a sailor or engine-driver should be able to recognize a red, green, or white light by its character of redness, greenness, or whiteness, respectively; that is to say, that the examinee has definite ideas of colour, and is able to reason with respect to them. All persons who are not able, through physical defect, to have definite ideas of the standard colours, and to be able to distinguish between them, must be excluded from the marine and railway services.

In constructing a test for colour-blindness, we must not forget the element of colour-ignorance, because an engine-driver or sailor has to name a coloured light when he sees it, not to match it. He has to say to himself, "This is a red light, therefore there is danger;" and this is practically the same as if he made the observation out loud. Therefore, from the very commencement we have colour-names introduced, and it is impossible to exclude them. As I have said before, making a person name a colour is an advantage, because the colour-name excludes the element of shade. If, as some persons have said, testing by colour-names is useless, then the whole series of colour-names is useless. But if I say to a friend, "That tile is red," and he agrees with me, it is evident that one object, the colour of which is by him classed as red, is also classed as red by me. The ordinary colour-names, red, blue, yellow, and green, form excellent bases for classification.

The engine-driver is told that red is a "danger" signal, green a "caution" signal, and white an "all right" signal. Therefore, it is very necessary that he should know what is meant by these colours.

It must be noticed that it is on account of there being approximate and absolute psycho-physical units that such great difficulty has been found in constructing an adequate test for colour-blindness, as it is the approximate, and not the absolute psycho-physical units of which we wish to know the number. It will be seen that it is not merely a matter of shade as far as the colour-blind are concerned, but a distinct difference in tint. The normal-sighted could divide the green of the spectrum into yellow-green, green, and blue-green; and would, in the majority of cases, be able to range all greens under these three classes. As the two-unit colour-blind see two colours only, they must name colours in this way.

We wish to exclude all those individuals who are included in the following three classes:—

I. Those who possess a pyscho-physical colour-perception with three or less units.

II. Those who, whilst being able to perceive a greater number of units than three, have the red end of the spectrum shortened to a degree incompatible with their recognition of a red light at a distance of two miles.

III. Those who are affected with central scotoma for red or green.

I will now explain why these three classes of persons should be excluded.

With regard to the first class. This class includes the three-unit, the two-unit, and the one-unit, in accordance with the facts previously stated. The three-unit never, under ordinary circumstances, mistake green for red, but confuse green, purple, and gray. Colour is a feeble quality

of objects to them, and nervousness or excitement may reduce them to the condition of the two-unit colour-blind.

The two-unit regard green and red as almost but not quite identical, and this fact is one which it is nearly impossible to make a person, who has not thoroughly studied colour-blindness, comprehend—either the colour-blind himself, the public, or an unqualified examiner. They find that many colour-blind persons are able to recognize different colours, and correctly name them, and therefore set down the mistakes made to want of education in colours. It is astonishing with what accuracy many colour-blind (two-unit) persons name colours. I have met with several who were nearly always correct when they named a colour. One educated adult, in particular, had become so expert that he was often able to baffle attempts made by his friends to show that he was colour-blind. He was well aware of the fact of his being colour-blind, though, when I asked him the names of various coloured objects, he was nearly always correct, and did not content himself with using the ordinary colour-names, but employed such terms as cerise. He told me the method he adopted; he said all colours appeared modifications of blue and yellow. The brightest and purest yellow was yellow; slightly darker and not so pure, green; darker still, red. The brightest and most typical blue, violet; less bright, blue; blue, with a tinge of gray (dirty blue), purple; very impure blue, cerise. This colour appeared to him blue by day, yellow by gaslight.

We cannot wonder at the unfavourable comments of unqualified persons, when we consider that the large majority of recorded cases have been of school children and uneducated persons. This source of error I eliminated by using for my standard cases and the following ex-

periments only educated persons who had tried to train their colour-sense, and were well aware of the names of colours.

The following will show how it is that the colour-blind are able, under ordinary circumstances, to distinguish between the colours included in one of their units. All colours have not a similar degree of luminosity; thus, yellow is much the brightest colour. To the two-unit colour-blind, red, yellow, and green, have, as far as colour is concerned, a very similar appearance. They are not exactly alike in colour, because they are included in an approximate, not an absolute psycho-physical unit. Green looks a lighter and grayer colour than red. A normal-sighted person might be given a bundle of wools, consisting of three kinds; the first different tints of yellow, the second tints of yellow mixed with gray, the third shades of yellow—that is, yellow mixed with black. He would be able to arrange these in three groups with few mistakes.

With regard to the second class. It is very important that persons belonging to this class should be excluded, and yet none of the ordinarily used tests detect them. The rays of red at the extreme left of the spectrum are the most penetrating, as may be seen by looking at a light or the sun on a foggy day, or through several thicknesses of neutral glass. It is chiefly by these rays that we recognize a red light at a distance; and it is therefore of great importance that a sailor or engine-driver should be able to perceive them.

With regard to the third class. This condition is one in which a person might be able to distinguish colours easily when they are close to him, but fail to distinguish them at a distance, owing to the nerve-fibres supplying the central portion of his retina being impaired. As a light

at a distance occupies the central portion of the visual field, it is essential that the corresponding portion of the retina should be normal.

We also do not wish to exclude persons who, though partially colour-blind, have a colour-perception sufficient for all practical purposes.

With regard to the test to be used. If the persons to be tested have to distinguish between the standard red and green lights, these lights should be used as the basis of the test; because, if any other test were used, we should still have the same problem before us, from a practical point of view. A sailor might (with reason) object to any other test, and say that because he cannot distinguish between a green and a gray wool, it is no reason why he should be unable to distinguish between the red and green lights.

The candidates' capacity in this respect may be tested with a Lantern, which is described below.

Though the fitness of a candidate could be determined with the Lantern Test, the examiner, especially if inexperienced, would, in many cases, be in doubt as to whether a candidate had made a mistake through a slip, or from a definite colour defect. This is especially liable to occur when the candidate *is* slightly colour-blind, and therefore, in order to save time and aid the examiner in detecting colour-blind persons with certainty, I have constructed another test, which I have called the Classification Test, and which may be used as a preliminary to the examination with the Lantern Test.

A conscientious examiner will then have his diagnosis confirmed when the results of both tests agree, and when they differ (I have not yet come across a case in which they have) he will be able to go more thoroughly into the case.

A, B, C, D, handles moving slides in front of the aperture E, the light being reflected to the observer by the mirror F.

I will describe these two tests in detail.

I. The Lantern Test.—The apparatus of this test consists of a lantern and thirteen slides; seven slides containing coloured glasses, and six containing modifying glasses The slides are numbered as follows:—

Coloured Glasses	*Modifying Glasses.*
1. Standard Red, A and B.	7. Ground Glass.
2. Yellow.	8. Ribbed Glass.
3. Pure Green.	9. Neutral (No. i.).
4. Standard Green.	10. Neutral (No. ii.).
5. Blue.	11. Neutral (No. iii.).
6. Purple.	12. Neutral (No. iv.).

I have not given separate numbers to the two reds, but called them 1A and 1B, respectively. This I have done to show that the examinee is not expected to distinguish between them.

By using a lantern with slides containing standard red and green glass, we can obtain the necessary colours. But there are few colour-blind persons who cannot distinguish between the red and blue-green lights at a short distance. A simile will show how they are able to do this. If a normal-sighted person were to take two coloured glasses, green and blue-green, and place them in a lantern, at a short distance he would be able to distinguish between them with ease. He would see as much difference between them as the colour-blind (two-unit) do between the standard red and green. But as the distance became greater, he would find more and more difficulty in distinguishing between the green and blue-green; and it would be very unsafe to trust a ship or a train to his powers, especially when one light only was shown. The two-unit colour-blind find the same difficulty with the standard red and green. The intensity and character of the light should therefore be changed, without the know-

ledge of the candidate. This may be done effectually with certain kinds of neutral glass.

The glasses I use, like a mist or fog, are most transparent to the red rays at the extreme left of the spectrum, and, when several glasses are used together, the light allowed to pass through them has a distinctly reddish hue. The normal-sighted easily recognize coloured lights that have had their intensity diminished by these neutral glasses, but the colour-blind find great difficulty in distinguishing the colours under these circumstances.

As it is necessary for an examiner to have the fullest acquaintance with the apparatus he uses, I will describe in detail the principles which have guided me in the construction of the Lantern Test. To an ordinary observer the slides appear to have been glazed with pieces of coloured glass, presenting no particular features other than that they are of a very decided colour. As a matter of fact, they are pieces of glass which possess certain qualities not found in other specimens.

What is required in a test for colour-blindness is that dangerous persons should be certainly and easily detected.

With the Lantern Test this object is never overlooked. We wish to demonstrate that the persons rejected are incompetent to act, and can do so efficiently with this test.

In describing the apparatus to a person who is not acquainted with the phenomena of colour-blindness, the latter should be told that the test consists in naming coloured lights, which are shown unmodified and modified as they would be under ordinary atmospheric conditions. The neutral glasses represent fog, the ground glass mist, and the ribbed glass rain.

The first principle which guided me in the selection of colours may be illustrated in the following way. Let us

take an ordinary two-unit colour-blind, and, having given him the set of wools belonging to the Classification Test, ask him to pick out all the reds. On examining the pile of wools selected as red, it will be found that the majority are red, but in addition there will be some browns and yellow-greens. If he be then told to pick out the whole of the greens the greater number of those selected will be green, but there will be also grays, browns, and reds. In each case, it will be seen that the majority of wools are of the desired colour.

If another two-unit colour-blind be examined in the same way it will be found that, though he may not make exactly the same mistakes, he will in all probability pick out the same greens to put with the reds, and the same reds to put with the greens. The same result will be obtained if the colour-blind persons be asked to name a large number of colours. They will in most cases name the colour correctly. It will be noticed that the greens which were put with the reds when classifying the colours, will be called red in naming them. It is evident that the same idea has guided the colour-blind in each case.

This shows that, though a person may be red-green blind, he is not absolutely red-green blind in the sense of being totally unable to distinguish between the two colours. This is what we should expect, as the red and green are included in an approximate, not in an absolute psycho-physical unit. The fact that they are actually judging by colour may be demonstrated by giving them coloured materials of different kinds, or by asking them to name a large number of coloured objects. To a person with a spectrum of normal length and no neutral band in the blue-green, it is necessary that the colours, to be considered as identical, must be included in an absolute psycho-

physical unit. One of the most definite signs that persons with a neutral band in the blue-green have a more defective colour-perception than the ordinary two-unit, is that they will put together as identical a red and green which are distinguished by the ordinary two-unit. In addition to this, they will mistake the reds and greens which have been confused by the ordinary two-unit.

It will be seen that if we take a two-unit and ask him to name a number of red and green wools, in the majority of instances he will name them correctly. But as, almost invariably, the same wools are chosen, for all practical purposes the same result would be obtained by asking a person to name a few of these wools. What more decided and brighter greens could we have than Nos. 76 and 94 of my Pocket Test? yet these are two of the greens which are called reds by the two-unit. We should have accomplished as much by asking a colour-blind person to name Nos. 76 and 94 as if we had asked him to name a large number of greens. The colours in a test should, therefore, be those which the colour-blind are particularly liable to miscall. At the same time, their nature should be unmistakable to the normal-sighted.

This is the first principle on which the test is constructed. No. 3, Pure Green, is to the normal-sighted a very bright and decided green, and yet it is precisely the colour which is confused with red by the two-unit. No. 1B is a very decided red to the normal-sighted, and yet the two-unit colour-blind are particularly liable to call it green. Nos. 1A and 3, the Standard Red and Green, are colours which usually present very little difficulty to the colour-blind. Their special use is in combinations. No. 2, Yellow, is a deep orange-yellow which gives a light of lower luminosity than the flame alone. It is generally mistaken by the colour-blind for red, and is a very useful

colour. No. 5, Blue, is as pure a blue as can be obtained with a single piece of glass. It and No. 6, Purple, are liable to be miscalled in certain cases.

We now come to the six modifying glasses. These glasses are specially intended for combinations, but they are very useful when used as single slides. The ground glass spreads the light, and prevents the flame from being visible in the centre of the slide. The ribbed glass produces a light which varies in its intensity in different portions. The four neutral glasses are very valuable as single slides. Whilst the normal-sighted recognize the nature of the slide at once, I have not met with a colour-blind person (three-unit or two-unit) who has named the glasses correctly. The reason of this is as follows. The colour-blind (three-unit and two-unit) are under the impression that they can always recognize yellow. This is true enough as far as bright yellows are concerned, the superior luminosity of a bright yellow over that of other colours is a distinguishing characteristic. As a matter of fact, browns, which are only shades of yellow, are the colours which above all others present difficulty to the colour-blind. The difference in luminosity between a yellow light, like that of an ordinary street lamp, and a coloured light, is not as great as the difference in luminosity between a yellow and a green wool. If, therefore, we can diminish the luminosity without altering the colour of a yellow light, we shall produce a colour which will present exceptional difficulties to the colour-blind. The light will therefore be called red or green as the case may be. To the three-unit, yellow is a reddish green as far as colour is concerned. No. 9 rather inclines to the red side of the red-green, and is usually called red by those who have a spectrum of normal length, and green by those who have a spectrum shortened at the red end. No. 10

inclines to the green side of the red-green, Nos. 11 and 12 to the red side. As the four-unit see yellow as a colour, it is obvious that the light will appear more like this colour to them than any other, and so will be named correctly.

The second principle which has guided me in the construction of this test is, that the colour-blind will name colours in accordance with their psycho-physical colour-perception, and thus show definitely to which class they belong. I have not come across a man who has guessed correctly when examined with my test. A man who did guess would know that he was incompetent. As the colour-blind are often not aware of their defect they answer as they see, only guessing when they feel uncertain as to the nature of the colour shown.

The third principle of the test is that colours may be changed to the colour-blind, whilst leaving them unaltered to the normal-sighted. This we should expect from an examination of the theory of psycho-physical perception. By referring to the frontispiece it will be seen that the junctions of the units do not correspond in the different classes of colour-blind, even for the simple colours. The blue-green junction of the four-unit is situated in the blue of the normal-sighted. If therefore we have two blues, one corresponding to a point on the green side of this junction, and the other to a point on the violet side, it is evident that the first blue would be called green by the four-unit, and the second blue, violet. If, therefore, we can alter a colour which corresponds to the first point so that it shall correspond to the second point, we shall have changed the colour from green to violet for the four-unit, whilst still leaving it blue to the normal-sighted. This result may be accomplished by means of absorption. If rays be taken from the violet side of a blue, the colour will correspond to a point of the spectrum nearer the green.

The fourth principle of the test is that the phenomena of simultaneous contrast are much more marked for the colour-blind than for the normal-sighted. Two colours, which have not changed in the slightest degree to the normal-sighted on being contrasted have apparently altered very considerably to the colour-blind. As an example of this, let us take a pure deep yellow, a bright red, and a bright green. To the normal-sighted the yellow will be altered very little by comparison with the red or the green, but a three-unit would say that the colour was green when contrasted with the red, red when contrasted with the green. This principle of exaggerated contrast must be borne in mind when examining a candidate. Thus, if a three-unit is doubtful as to what to call a yellow, but seems inclined to call it green, he should be given a pure green to compare with it. In the same way, in showing the coloured lights, the same colour produced in a different way should often be shown. Thus an orange-red may be shown immediately after a pure red. This will not alter the colour to the normal-sighted, but greatly facilitate the examination of the colour-blind. It seemed to me that, as the psycho-physical colour-units of the colour-blind were larger than those of the normal-sighted, it must follow that the modified units would also be larger. For instance, take the three-unit, their modified unit red-green would be much larger than any modified unit of the normal-sighted. When we are dealing with an absolute psycho-physical unit, we know that though this unit may occupy some considerable portion of the spectrum, the colours at each of its parts are indistinguishable from each other. The modified unit red-green of the three-unit will therefore extend into the green of the normal-sighted. Theoretically, therefore, we can change the colour of a coloured light to the colour-blind without

altering its appearance to the normal-sighted. All we theoretically have to do is to move the colour into the modified unit of the colour-blind. This is done by the neutral glasses. The coloured glasses are also chosen in accordance with the above principles. The Standard Green lets through very few red rays, the Pure Green is much less opaque to these rays. The Standard Red, 1B, lets through, besides the red and orange rays, some of the green. Let us, then, consider the aspect of the light with the Standard Red, 1B, and the thickest neutral glass in front of it. This neutral glass only transmits a band of the extreme red, and a band of yellow-green. To the normal-sighted the colour of the combination is a very bright red. The three-unit will either confess that they do not know what the colour is, or give an answer depending upon the colour previously shown; if red were shown previously, then they will call the colour "green" obediently to the law of contrast. With the two-unit the colour will be called "green," usually with some positive exclamation. In all the examinations I have made, I have only come across one two-unit who called this combination correctly "red." He, however, called the standard green, pure green, yellow, and blue in combination with this glass also "red." In the case of shortening of the red end of the spectrum to the extent of about one-third, the red light will not be perceived at all. The neutral glasses, therefore, make the red appear like the green of the colour-blind, and the green like the red. No. i. Neutral simply diminishes the intensity of the light, making it, if anything, whiter. No. ii. Neutral imparts a faintly greenish tinge to the light; No. iii. Neutral imparts an orange tint to the light; and No. iv. Neutral a reddish tinge. It will be noticed that No. ii. is of a slightly different character to the others.

As it is necessary that the examiner should be fully acquainted with the details of this test, I will give an analysis of the light which is transmitted through the different glasses. At first sight the test appears as if it were one in which simple coloured glasses were shown to the examinee, alone, and combined with other glasses to represent rain, mist, and fog. These conditions are actually represented by the test. But the representation of these conditions was not the primary idea which I had in constructing a test for colour-blindness. I mention this because, after I had published my views on testing for colour-blindness numerous tests in which fog, etc., are supposed to be represented have been recommended.

It will be noticed that there are two slides marked "1, Standard Red." To a normal-sighted person these slides appear to be of a very similar colour, the only difference being that the one marked B is slightly lighter than the slide marked A. The importance of having these two slides is really very great, as they differ considerably in their transparency to the rays of the spectrum. No. 1A is practically only transparent to the red and orange, and, when combined with the blue-green slide, No. 4, it is hardly possible to see the light. No. 1B is transparent to the red, orange, and yellow, and a number of green rays are transmitted. This may be demonstrated by combining it with the blue-green slide. No. 4, and the flame will appear yellow-green. The reason for having two slides is as follows. If we examine an ordinary two-unit with 1A + 12, we shall find, if he have much shortening, that he is not able to see the light at all. 1B shows how a person who belongs to a class with a greater number of units than two might mistake red for green. 1B + 12 gives a light which, to the normal-sighted, is of a deep red colour, similar to but slightly lighter than that produced

with 1A + 12. But the composition of these lights, if examined with the spectroscope, will be found to be very different in the two cases. The light produced by 1A + 12 is a light consisting entirely of red rays belonging to the extreme left of the spectrum. The light produced by 1B + 12 consists of similar red rays, but in addition contains a number of yellow-green rays. These may be demonstrated by the combination 1B + 12 + 4. The light will then appear of a dull green. With the combination 1B + 12, if there be much shortening, these rays will have to be subtracted, and so the light will really appear of a green colour, because the green element in the combination will be considerably in excess. This combination is therefore useful in excluding cases of shortening of the red end of the spectrum, occurring under any circumstances.

The examiner should make himself familiar with all the details of the slides, and the colours of different combinations. The purest blue is produced by the combination 5 + 4. No. 4 by itself gives a light of a lavender colour, on account of the transmission of a good many red rays. The blue-green glass is opaque to these, and so the blue is very much purer.

The following is an analysis, with a spectroscope, of the light transmitted through the glasses used in the Lantern Test.

1A. The red and orange rays are transmitted, but the remainder of the spectrum is obstructed.

1B. This glass allows the red and orange rays to pass. There is a defined absorption band at the junction of the yellow and green. The green, blue, and violet rays are almost but not quite obstructed.

2. There is no definite absorption band. The violet rays are most obstructed, then the blue and then the

green. The red, orange, and yellow rays are allowed to pass.

3. The glass is opaque to the red rays, and almost opaque to the blue and violet rays. It is transparent to the green rays, and allows a considerable number of the yellow and orange rays to pass.

4. The red and orange rays are obstructed. The glass is transparent to the green, blue, and violet rays. A few yellow rays are allowed to pass.

5. This glass is transparent to the blue rays and a band of red at the end of the spectrum. Defined absorption bands are visible in the red, and in the yellow and orange-yellow. The glass is transparent to a band of orange-red. The violet and green rays are obstructed to a certain extent; of these the yellow-green are most visible.

6. This glass is most transparent to a band of red at the extreme left of the spectrum. There are absorption bands in the centre of the green, red, orange, and yellow. The remainder of the green, red, orange, and yellow is obstructed to a certain extent. After the above-mentioned band of red the glass is most transparent to the violet, blue, and blue-green rays.

7 and 8. These glasses diminish the luminosity of the whole of the spectrum. There are no absorption bands visible.

9. This glass impairs the brilliancy of the whole of the spectrum, but especially the green, blue, and violet half. No absorption bands are visible.

10. This glass has a similar effect upon the spectrum to No. 9, but the changes are more marked.

11. This glass is most transparent to a band of red at the extreme left of the spectrum, the orange and yellow-green. There are definite absorption bands in the red and

in the yellow. A few only of the green, blue and violet rays are transmitted.

12. This glass is most transparent to a band of terminal red, and a band of yellow-green. The glass is almost opaque to the green, blue, and violet rays, and quite opaque to the remainder of the spectrum.

The following colours are produced by combining the various slides of the test. Nos. 7 and 8 do not alter the colour of the light, but scatter it. No. 7, Ground Glass in combination with a coloured glass produces a circle of uniform colour, but rarely alters the colour of the light to the colour-blind. The same may be said of No. 7, which in combination with a coloured glass gives a field of colour the various portions of which vary in intensity.

1A + 2 = red. 1A + 3 = reddish orange; the flame only is visible. 1A + 4 = black; the flame is just visible, but has no colour. 1A + 5 = deeper red. 1A + 6 = deeper red. 1A + 9 = deeper red. 1A + 10 = deeper red. 1A + 11 = deeper red. 1A + 12 = very deep red; in this combination the flame only is visible.

1B + 2 = red. 1B + 3 = yellow. 1B + 4 = green. 1B + 5 = red. 1B + 6 = red. 1B + 9 = red. 1B + 10 = red. 1B + 11 = deep red. 1B + 12 = very deep red.

2 + 3 = yellow-green. 2 + 4 = pure green. 2 + 5 = white. 2 + 6 = crimson. 2 + 9 = orange-yellow. 2 + 10 = orange-yellow. 2 + 11 = orange. 2 + 12 = orange.

3 + 4 = pure green. 3 + 5 = pure green. 3 + 6 = greenish blue. 3 + 9 = green. 3 + 10 = green. 3 + 11 = green. 3 + 12 = very dark green.

4 + 5 = pure light blue. 4 + 6 = pure dark blue. 4 + 9 = blue-green. 4 + 10 = blue-green. 4 + 11 = dark blue-green. 4 + 12 = very dark blue-green.

5 + 6 = purple. 5 + 9 = lavender. 5 + 10 = lavender. 5 + 11 = rose. 5 + 12 = dark crimson.

6 + 9 = purple. 6 + 10 = purple. 6 + 11 = crimson. 6 + 12 = crimson-red.

7 + 8 = yellow. 7 + 9 = yellow. 7 + 10 = white. 7 + 11 = white. 7 + 12 = dull orange.

8 + 9 = white. 8 + 10 = white. 8 + 11 = white. 8 + 12 = dull orange.

9 + 10 = white. 9 + 11 = dark yellow. 9 + 12 = dark orange.

10 + 11 = yellow. 10 + 12 = dark orange.

11 + 12 = dull crimson.

1A + 2 with 1B, 5, 6, 7, 8, 9, 10, 11, and 12 respectively, gives a red light. 1A + 2 + 3 = reddish orange. 1A + 2 + 4 = black. 1A + 3 + 1B = orange-red. 1A + 3 + 9 = dull orange-red. 1A + 3 + 10 = very dark orange-red. 1A + 3 with 5, 6, 11, and 12 respectively, black. 1A + 5 with 1B, 6, 7, 8, 9, 10, 11, and 12 respectively, red. 1A + 6 with 7, 8, 9, 10, 11, and 12 respectively, red.

1B + 2 + 3 = yellow. 1B + 2 + 4 = dull green. 1B + 2 with 5, 6, 7, 8, 9, 10, 11, and 12 respectively, red. 1B + 3 + 4 = green. 1B + 3 + 5 = dull green. 1B + 3 + 6 = black. 1B + 3 with 7, 8, 9, and 10 respectively, yellow. 1B + 3 + 11; a light can just be seen, but there is no colour. 1B + 3 + 12 = black. 1B + 4 + 5 = greenish blue. 1B + 4 + 6 = very dull blue. 1B + 4 with 7, 8, 9, and 10 respectively, green. 1B + 4 + 11 = very dark green. 1B + 4 + 12 = black. 1B + 5 with 6, 7, 8, 9, 10, 11, and 12 respectively, red. 1B + 6 with 7, 8, 9, 10, 11, and 12 respectively, red.

2 + 3 with 5, 7, 8, 9, 10, and 11 respectively, green. 2 + 3 with 6 and 12 respectively, very dark green. 2 + 4 with 7, 8, 9, 10, and 11 respectively, green. 2 + 4 + 5 = blue-green. 2 + 4 + 6 = dark blue. 2 + 4 + 12 = very dark green. 2 + 5 + 6 = red. 2 + 5 with 7 and 8 respectively = white. 2 + 5 with 9 and 10 respectively, orange. 2 + 5 with 11 and 12 respectively, red. 2 + 6 with 7 and 8 respectively, crimson. 2 + 6 with 9 and 10 respectively, rose-red. 2 + 6 with 11 and 12 respectively, red. 2 + 9 with 7, 8, and 10 respectively, yellow. 2 + 9 + 11 = orange. 2 + 9 + 12 = dark orange-red. 2 + 10 + 11 = orange. 2 + 10 + 12 = dark orange-red. 2 + 11 + 12 = very dark orange-red.

3 + 4 + 6 = blue. 3 + 4 with 5, 7, 8, 9 10, and 11 respectively, green. 3 + 4 + 12 = very dark green. 3 + 6 + 8 = blue. 3 + 6 with 9 and 10 respectively, dark green-blue. 3 + 6 with 7, 11, and 12 respectively black.

4 + 5 with 6, 7, 8, 9, 10, and 11 respectively, blue. 4 + 5 + 12 = black.

5 + 6 with 7, 8, 9, and 10 respectively, purple. 5 + 6 + 11 = rose. 5 + 6 + 12 = rose-red. 5 + 9 + 10 = purplish lavender. 5 + 9 + 11 = rose. 5 + 9 + 12 = rose-red. 5 + 10 + 11 = rose. 5 + 10 + 12 = rose-red. 5 + 11 + 12 = red.

6 + 9 + 10 = purple. 6 + 9 + 11 = rose. 6 + 9 + 12 = red. 6 + 10 + 11 = rose. 6 + 10 + 12 = red. 6 + 11 + 12 = red.

7 + 8 with 9, 10, and 11 respectively, white. 7 + 8 + 12 = brown. It must be noted that 9 and 10 with 7 give a greenish tinge to the light. 7 + 11 is quite neutral. 7 + 12 is a reddish white. 7 + 9 + 10 = white

7 + 9 + 11 = brown. 7 + 9 + 12 = dark brown. 7 + 10 + 11 = neutral. 7 + 12 with 10 and 11 respectively, black.

8 + 9 + 10 = white. 8 + 9 with 11 and 12 respectively, brown. 8 + 10 with 11 and 12 respectively, brown. 8 + 11 + 12 = reddish brown.

9 + 10 + 11 = whitish purple. 9 + 10 + 12 = dull purple.

10 + 11 + 12 = dark red.

Description of Classification Test.—This test consists of 4 test-colours and 180 confusion-colours; 150 coloured wools, 10 skeins of silk, 10 small squares of coloured cardboard, and 10 small squares of coloured glass. The whole series of colours is represented, both the simple and the modified units. In addition, there are a large number of colours which have been chosen by colour-blind persons as matching the test colours. The test-colours are Orange, Violet, Red, and Blue-green, labelled I., II., III., and IV., respectively. The whole series of colours is chosen with the view of presenting as much difficulty as possible to the colour-blind, and as little as possible to the normal-sighted. The colour-blind find especial difficulty in matching or naming a colour lying at the junction of two of their units or colours. As the normal-sighted often find difficulty in saying which colour predominates in a blue-green, so do the four-unit with what they call a purple-green, or the three-unit with what they call a red-green. It is obvious, therefore, that if a colour-blind person can be made to understand what colour is, he may match a colour correctly which corresponds to the centre of one of his units. I have never detected an educated four-unit with Holmgren's test, whereas an uneducated four-unit is almost certain to fail through paying more attention to shade than to colour.

In addition to choosing those colours for tests which are particularly liable to be mistaken for other colours by the colour-blind, I have used coloured materials of different kinds—wools, silks, glass and cards,—so as to

force the colour-blind to judge by colour, and not by shade or luminosity.

The first test-colour is orange, which is the first unit to disappear, and, therefore, in the first degree of colour-blindness it becomes a modified, instead of a primary psycho-physical colour unit. As the psycho-physical colour-units become enlarged, so do the number of mistakes which are made with this colour, increase. Giving an orange to a colour-blind person to match is like giving a blue-green, in which the proportions of blue and green are nearly equal, to a normal-sighted person, who would certainly put blue-greens on the one hand and green-blues on the other with the test-colour. Test-colour No. II. is as nearly as possible a pure violet, and represents the violet half of the spectrum. No. III. is a pure red, and represents the red half of the spectrum. No. IV. is a blue-green, and represents the remaining portion of the spectrum. The green element predominates very considerably, and so the normal-sighted will only select shades of green to put with it. This is an important colour, and the necessity for choosing this shade will be evident on reading the method of using the test.

Those who are unacquainted with the phenomena of colour-blindness, would not be able to educate themselves with the Lantern Test, as this is essentially a testing apparatus, and not intended for educational purposes. The Classification Test is constructed so that the examiner may be able to follow the observations described in Chapter XI. In that chapter the reader is recommended to get the colour-blind person to make a general classification of colours, but it will be found that the mistakes made with the test-colours will generally be indicative of the nature of the case. The use of different materials will prevent the colour-blind from judging by accessory qualities of the materials.

The following preliminary instructions will be found useful, both for the examiner and the examinee.

The first point is to put the candidate at his ease, and these instructions, for this purpose, cannot be too widely known amongst those men who are going to be examined. It will save the examiner much trouble if the instructions be issued in the form of a circular to all intending candidates. The following might be the form of the circular:—

Advice to Candidates Presenting themselves for Examination in Colours.

The colours which the candidate is expected to know are Red, Yellow, Green, Blue, and Purple. Candidates are expected to know the names and qualities of these colours, and should make themselves thoroughly acquainted with the appearance of lights of these colours. Persons possessing normal sight or only slightly colour-blind will find no difficulty in passing this test. They will only be shown colours of the most marked character, and those which they will meet with every day in the pursuit of their employment. A candidate will be rejected who cannot distinguish between the red, green, and white (yellow) lights under all the circumstances in which they will be presented to him. In his employment these are the three colours which he will have to distinguish between, and if he find that he can distinguish between these lights on a railway, under various conditions of atmosphere, he will in all probability find no difficulty in passing this test.

As one mistake in naming red, green, or white, will suffice for his rejection, a candidate is particularly cautioned against guessing or trying to imagine a colour when there is not one presented. If a candidate find

difficulty in naming a colour he should at once say so, because any answer showing that the candidate sees the light correctly will be taken. Thus mauve, violet, or reddish blue would be taken as correct descriptions of the purple light. The candidate, however, is strongly advised to learn the correct names and qualities of orange and violet. The answers yellowish red or reddish yellow would however, be taken as correct definitions of combinations presenting an orange colour.

A candidate cannot have too firmly impressed upon his mind that there is no difficulty in the test to a normal-sighted person. The only chance that a normal-sighted person stands of failing is by guessing or trying to imagine a colour when there is not one there. If candidates follow this advice they will be saved the trouble of an appeal. It is necessary to reject a man for making one mistake, because guessing or colour-ignorance would make a man dangerous when following his employment.

The wools in the first part of the test are used entirely as a matter of convenience, so that colour-blind persons may be rapidly and certainly rejected; but the candidate is passed or rejected in accordance with the examination with coloured lights.

Examination for Visual Acuity.—The candidate should first be tested with regard to his visual acuity, each eye being tested separately. Snellen's types, or a modification of them, will answer admirably for this purpose. A very useful modification of Snellen's types is made by Meyrowitz, 1a Old Bond Street, W.; the last line but one of the types can be read by a normal-sighted person at a distance of six metres. The examiner should have at least half a dozen sets of types, so that a candidate

shall not be able to learn the letters by heart, and repeat them to another candidate.

A candidate should not be passed who has not normal visual acuity with one eye, and not less than half with the other.

Examination with Classification Test.—The candidate should first be examined with the Classification Test. He should be given the four test-colours, and, having given the name of each, he should be told to select all those which are similar in colour to the test-colour. He should be told to pay no attention to the fact of a colour being lighter or darker, as long as it is the same colour it should be put with the test-skein. The examiner should not go through the test before the candidate first of all, neither should one candidate be allowed to watch another making his selection. A shrewd colour-blind person might pass the test if he had seen a normal-sighted person go through it previously. In order to show the candidate the difference between a shade and a colour, the examiner should take one of the wools which is not a test-colour, blue, for instance, and pick out four or five shades of the colour.

The examinee may pick out a certain number of colours correctly and then stop, saying that there are no more exactly like the test-colour; and this may embarrass the examiner. He should, however, examine any candidate who has omitted any colours as carefully as if mistakes had been made. He should ask the candidate to match one of the omitted colours.

The following short summary of the mistakes made by the different varieties of the colour-blind will help the examiner in forming his diagnosis.

The five-unit put red and pink with the orange test No. I. It will also be found that they have not

matched the other test-skeins as accurately as the normal-sighted.

The four-unit, in addition to putting red and pink with the orange test, put blue with the violet test. They will also probably put some light blues with the green test-skein.

The three-unit put red, rose-red, and yellow-brown with the orange test; purple and blue with the violet; and rose, gray, brown, and blue with the green test-skein.

The two-unit put red, yellow, yellow-brown, and yellow-green with the orange test; blue and purple with the violet test; and gray, brown, and rose with the green test.

If black be put with the red test, there is shortening of the red end of the spectrum. Shortening of the red end of the spectrum is also indicated by dark greens being put with the red test.

As the border-line of rejection is between the four-unit and the three-unit, it is of great importance to be able to say for certain to which of the two classes a person belongs. A four-unit does not put brown, rose, or gray with green; a three-unit does not necessarily put all these colours with green; it is sufficient if he put one of them. If there is any doubt as to whether a person is a four-unit or a three-unit, he should be asked to classify the whole of the colours in the test, putting all of one colour together. There will then be very little difficulty in making an accurate diagnosis.

Examination with Lantern Test.—The examination with the lantern completes the examination for visual acuity and colour-perception. It is the essential test, and the one which demonstrates perfectly to an onlooker the incompetence of those rejected.

The object of the test is to find out whether the candidate can distinguish, under all circumstances, the red,

green, and white lights. The colours, other than the red and green, are used to prevent guessing.

The following short directions are issued with each set of apparatus, and will serve to keep before the examiner the important points of the test:—

1. The candidate should be seated at a distance of fifteen feet from the lantern.

2. He should be asked to name the colour of the light produced by a coloured glass (1 to 6) alone, or in combination with the modifying glasses (7 to 12).

3. A candidate should be rejected—(i.) If he call the red, green; or the green, red, under any circumstances. (ii.) If he call the white light, under any circumstances, red or green, or *vice versâ*. (iii.) If he call the red, green, or white lights, black, under any circumstances.

4. A candidate who makes mistakes, other than those mentioned above, should be put through a very searching examination.

In making an examination with this test, the candidate should be at least fifteen feet from the lantern. I have given fifteen feet as the distance because in many cases it would be difficult to make the distance greater, and this will be found sufficient for all practical purposes. When it is possible to make the examination in a room in which the candidate can be seated at a distance of twenty feet from the lantern, this should be done, as it increases the certainty with which colour-blind persons are detected. In the same way, a distance of sixteen feet would be preferable to fifteen feet, and so on, up to twenty feet. The distance used should in each case be noted in the report.

The examiner should on no account conduct the examination on any regular plan, because the candidate, anxious to pass, finds out from persons who have already

passed, the order and method of the examination, and so, though colour-blind, might obtain a certificate.

Any one of the slides may be first shown, and the candidate required to name the colour of the light. The following will serve as an example of the method to be employed in testing a candidate. The standard red slide having been placed in the lantern, the candidate is required to name its colour. Then a blue or green slide may be substituted. Then one of the neutral, ground or ribbed glass slides should be inserted, not the slightest intimation being given to the candidate of the nature of the slide. He should be asked to name or describe the light, and the answer, if incorrect, together with his other replies, carefully recorded. The other slides may then be shown, a combination of the neutral, ground, ribbed and coloured glasses being used at irregular intervals.

Care must be taken when the candidate is going to be examined with two slides at once, such as one of the neutral, ground, or ribbed glasses, and a coloured glass, that he does not see the light until both slides have been inserted, or else he may see the colour before it is modified in the necessary way.

Another practical point to be borne in mind is, that the modifying glass should be placed in *front* of the coloured glass, and not between it and the light, just as the fog or mist is in front of the signal glass, and not behind it.

If the candidate call the standard red, green; or the standard green, red, under any circumstances—that is, either alone, or in combination with the modifying glasses—he is to be rejected.

Particular attention should be paid to the answers given to the combination of the thickest neutral glass with the standard red and green respectively. This glass is of

such a thickness that it obstructs all light with the exception of a band of red at the extreme left of the spectrum, and a band of green. This glass, when used in combination with the Standard Red 1A, gives a red light, visible to the normal-sighted at a considerable distance. With the colour-blind, if the red end of the spectrum be much shortened, the red light will not be perceived at all. In combination with the standard green, it gives a dull green light, which is easily recognized by the normal-sighted.

It will be noticed that with this glass the relative intensity and character of the red and green lights are changed. With the unmodified lights, the green is lighter and bluer than the red. When modified with this neutral glass, the green appears the darker and yellower of the two, exactly as it does in a mist or fog. The two-unit colour-blind, therefore, at once call this combination red, because the colour is made to look so much like their red. I have not met with a two-unit colour-blind who has named this combination correctly; the answer has almost invariably been "red," usually with some positive exclamation; as, "There is no doubt about *that* being red." The importance of this fact cannot be over-estimated, because I have tested educated colour-blind persons who have found no difficulty in naming the colours when unmodified with neutral glasses, and so would have obtained a certificate.

These would be most dangerous persons at sea, because they would deliberately mistake the red light for the green, and *vice versâ*. At the same time they would feel positive about the nature of the lights. It seems to me that in all probability this is how many accidents have occurred.

If the candidate call the white light, under any cir-

cumstances, red or green, or *vice versâ*, he is to be rejected. Also, if he call the red, green, or white lights "black," under any circumstances.

As it is the confusion of red, green, and white which forms ground for rejection, in examining with the neutral glasses the examiner should be guided by this point. Thus a neutral glass may give a reddish tinge to the light; a candidate calling the light "red" might be reconsidered, whilst a candidate calling the light "green" would be rejected without further consideration.

The white light which is used for signal-lights is really yellow, but I have referred to it as white because this is the name by which it is generally known. In the examination an answer calling the yellow slide white, might be taken as correct. In the same way the ground glass might be called yellow, but if the candidate call either "red" or "green" he should be rejected. As I have previously stated, the confusion of yellow with red or green, indicates a dangerous degree of colour-blindness.

One incorrect answer (embodying one of the mistakes mentioned above) suffices for rejection. This is important, and must be strictly adhered to. A normal-sighted person would not mistake the colours confused by the colour-blind. Colour-ignorance is quite as fatal (*if* the mistakes were due to this cause) as colour-blindness; thus, if a sailor, on seeing a red light, *thought* it was a green one, and steered as directed for a green light, he would cause an accident just as surely as if he were colour-blind.

A candidate who has made one mistake, and one mistake only, may be passed on to a specialist, but should never be passed by an examiner not thoroughly acquainted with all the theoretical and practical details of colour-blindness.

An examiner should, as far as possible, avoid all conversation with the candidate, simply asking, "What colour is this?" and recording the answer without comment. If an examiner after each answer say, "Quite right," or some such expression, the following is likely to occur. The candidate after, say, six correct answers, makes a mistake; the examiner says, "Are you sure?" Then the candidate knows at once that he has made a mistake, and makes a guess, very probably a correct one. When a similar colour is shown subsequently, he remembers the mistake he made, and gives the second, and probably the correct answer.

Mistakes other than those mentioned above demand a very searching examination.

I have already mentioned the special uses of certain glasses and combinations, but, in order to make the examiner's work easier, I will go through the most important combinations systematically.

1A, 7, and 8 are not of much use as single slides, and errors are rarely made in naming them, when presented alone; 2, 3, 9, 10, 11, and 12, are the slides which are specially useful when used singly.

1A + 4 is a combination which may be used occasionally, so that the candidates may know that a black is sometimes shown to them. If a black were never shown, a colour-blind person, with shortening of the red end of the spectrum, would hesitate to call any combination "black."

1B + 3 gives a yellow light which is especially liable to be mistaken for red or green by the colour-blind. 1B + 4 gives a green which most two-units would mistake for red.

2 + 3, 2 + 5, 2 + 6, and 2 with 9, 10, 11, and 12, are all useful combinations. The combinations of the neutral glasses, 11 and 12, with the reds and greens are

particularly useful; in fact, 11 and 12, in combination with any of the coloured glasses, give lights which should be used frequently. 8 + 12 and 9 + 11 are useful combinations. 1B + 2 + 3 and 1B + 2 + 4, should be used occasionally; also 1B + 3 + 9 and 1B + 3 + 10. The following are also useful combinations, 1B + 4 + 6, 1B + 4 + 11, 2 + 3 + 6, and 2 + 3 + 12.

On reconsidering this test, we find that it is not open to any objections. The material is the best possible, as it will not fade like all dyed substances, and therefore all records made with one set of apparatus will be uniform. Again, a coloured light has none of the accessory qualities which enable the colour-blind to pass through other tests. Thus many two-unit colour-blind will call the yellow glass red or green, who would not think of putting a yellow with a green or red wool, on account of the difference in luminosity. The test is not open to any of the objections which may be urged against the method of simply naming colours, because the character and intensity of the colour may be changed at will.

The method is better than that of direct comparison, because the candidate is forced to use his colour-perception, and has to compare the colour seen, with previous impressions of colour in his mind. By the use of neutral glasses, etc., I have obviated the fallacy of the method of naming colours (namely, that an individual can distinguish between colours by their intensity), and forced the individual to depend upon his colour-perception, and not upon some other accessory quality of the object seen.

No amount of coaching will enable a colour-blind person to pass this test, whilst almost any other may be passed in this way.

The test also has a quality, possessed by no other, namely, that of enabling the examiner to reject dangerous

persons and dangerous persons only, the lower degrees of colour-blindness being allowed to pass.

The next point to consider is when the test shall be concluded, because with the thirteen slides a very large number of combinations may be made. Twenty correct answers may be considered amply sufficient for a pass certificate. It would be practically impossible for a colour-blind person to guess this number of answers correctly. As a matter of fact, I have never examined a man who has tried to pass my tests by guessing. Colour-blind persons do not know that they are colour-blind, and therefore answer as they see. If they were to guess, they would have to admit to themselves that they were incompetent, and then they would not be so dangerous. Guessing depends more upon the self-reliance of the candidate. A self-reliant colour-blind man is far less likely to guess than a normal-sighted person who has a poor opinion of his own powers. Guessing may be prevented by the preliminary instructions which I have given.

In testing for colour-blindness, it must not be supposed that a colour-blind person will be detected if the testing be carried on in a perfunctory manner. The nature of colour-blindness must be borne in mind, special attention being paid to the fact that the colour-blind person has never seen in any other way, and therefore colour-names are associated with the small differences which he is enabled to detect. Special attention must be paid to the fact that the colour-blind do not necessarily miscall colours, in fact there is the greatest tendency to name them correctly. Thus, if we ask a two-unit colour-blind to pick out all the reds in a bundle of wools, the majority of the wools selected will be red. In fact, with a very intelligent colour-blind person, when only wools are used, no other colours may be added.

The examiner must always be on his guard against tricks and various subterfuges adopted by the colour-blind.

Qualifications of Examiners.—With regard to the persons who should conduct the examinations for colour-blindness, there seems to me no doubt that the testing should be conducted by a medical man specially trained in colour-blindness. I must say most emphatically that it is useless for a person who is not acquainted with the phenomena of colour-blindness to test for the presence of this defect. The cases of colour-blindness vary in so many particulars, that considerable experience will be required before an examiner is competent to pass or reject candidates for the marine or railway services.

The nature of the test has nothing to do with this; the facts are there, and only require to be detected. It is as useless to set an inexperienced person to test for colour-blindness, as it is to ask a student who has only a rudimentary knowledge of the use of the opthalmoscope to diagnose some retinal affection from a description in a book. Again, it must be remembered that a colour-blind person has never seen colours as the normal-sighted see them, and therefore is not acquainted with the nature of his defect. We have equally to test stupid as well as very shrewd persons.

At the present time there is no guarantee that the examiner himself is not colour-blind. An examiner should belong to the class of the six-unit, and be acquainted with the common diseases of the eye.

A reliable examiner will not be made in a day; an experience of several months at least will be required, and, to my mind, it is doubtful whether a non-professional man would ever be able to make an efficient examiner, so hard is it to eradicate certain prejudices and conclusions.

Re-examinations.—The probability is that a person who has failed in the examination as described in the foregoing pages is colour-blind, and will remain so to the end of his life. In the experience of those who are most qualified to form an opinion, colour-blindness is incurable and therefore a person who has once failed should be submitted to a very careful examination before he is passed, if examined a second time. I see no reason to restrict the number of re-examinations; what is wanted is not to exclude normal-sighted persons, but only those who are colour-blind. However, a person who has once been rejected should be required to pay a fee for a second examination, which should be doubled in the case of a third or subsequent examination. I have not in my experience met with a person who has passed at a second or third examination, though I have examined persons repeatedly in order to find out whether colour-blindness might be curable. It is, however, perfectly certain that, where there are a number of examiners, a few persons will be rejected who are normal-sighted, but have miscalled the colours through nervousness or ignorance. It is for the benefit of these persons that I recommend that re-examinations should be adopted.

On re-examining a person who has previously failed, the examination should be conducted on precisely similar lines to a first examination. Should the person examined again fail, the examination may cease. Should he pass, he should be referred to the head examiner, who should test him by making him classify about five hundred pieces of coloured material, and examine him with the spectrum, in the way described in Chapter XI. Should he pass these tests, he may be regarded as a person who has previously failed through nervousness or colour-ignorance.

I think that it is unnecessary, without some definite

reason, to re-examine those who have previously passed an examination.

The most essential point in testing for colour-blindness is to exclude those who are congenitally colour-blind. These persons stand on a very different footing to those who have become colour-blind after some years' service. There is this important point of difference between acquired and congenital colour-blindness—a person in the former case *knows* that he is colour-blind, but persons suffering from the latter defect are, in the majority of cases, ignorant of the fact. In the one case, therefore, a man is responsible for any accident which he might cause, in the other he is not.

In the case of acquired colour-blindness it is impossible that the man should not be cognizant of his defect. He has seen colours at one time as the normal-sighted see them, and therefore, having this remembrance, and daily having to distinguish colours, he would at once notice any falling off in his powers in this respect. Unlike a person who has very little to do with colours, he could not plead ignorance of his defect. He would know the points from which he could distinguish certain signals, and he could not help noticing any change in their appearance.

The first examination is the essential one, and should be conducted in such a manner as to exclude all dangerous cases of colour-blindness, congenital or acquired. Each man passing this examination should be given a certificate of competency.

A further examination will only be required under special circumstances, which are:—

1. If the man has complained of his sight for any reason whatever.

2. If for any reason the man's sight be called in question.

3. On transfer from a department in which it was not necessary to distinguish between colours to one in which this qualification is necessary.

4. In all cases in which accidents have occurred which might be due to colour-blindness.

Those employing the men might help very considerably in cases in which the colour-blindness is acquired, by transferring a man who has given notice that he is becoming colour-blind, after the fact has been confirmed by examination, to some department where it is not necessary to distinguish between coloured lights. If a man were to be discharged when he reported that he was becoming colour-blind, there are many who, through thinking of their wives and families, would be inclined to conceal the defect; whereas, if the course which I have recommended be adopted, not only colour-blind men, but men suffering from defective sight arising from any cause, would be induced to accept positions where they would not be so dangerous to other people. Cataract, and the majority of the diseases of the eye, render a man quite as unfit for acting as a look-out man or engine-driver as colour-blindness does.

The Colour Tests described in this chapter are made by Meyrowitz, 1a *Old Bond Street, W.*

CHAPTER XXI.

OBJECTIONS TO THE TESTS FOR COLOUR-BLINDNESS IN GENERAL USE.

1. An Examination with Coloured Lights.—The first idea which would naturally occur to any one wishing to test persons, who would in their employment have to distinguish between the red, green, and white (yellow) lights, would be to test them with these lights as occurring in their employment: for instance, in testing a candidate for employment as engine-driver, to take him at night to some junction where a large number of signal lights could be seen, and ask him to name the colour of the lights as they were pointed out to him. What, therefore, are the objections to testing in this way?

In the first place we can not obtain at will the varying atmospheric conditions which a man would meet with in his employment. Thus fog, rain, hail, and snow, each produce a different aspect of the light. So that even if we could wait until we obtained each of these conditions (which of course would be quite impracticable), we could not obtain the rapidly changing atmospheric conditions with which an engine-driver meets. He may have fine weather in one part of his journey, rain in another, and fog at the terminus. Again, a man, when he is standing still looking at a number of red and green lights, can compare the two, and so make up his mind which is the

red and which is the green. When running his train, he sees only one light, and has to decide quickly whether it is red or green.

As a matter of fact, colour-blind persons can, as a general rule, distinguish between the red and green lights, and so remain in the employment of a railway company for years without causing an accident, but one may occur at any moment through their physical defect.

I have taken a completely red-green colour-blind person to a place from which a number of signal lights were visible, and asked him to give me the name of each. This he did easily and without any mistakes.

2. Objections to Holmgren's Test.—This test is one which is well known, and has many advocates. It is one that has formed the basis for many others. Before proceeding to criticize his test, I must again offer my tribute to the value of Professor Holmgren's services in bringing the subject of colour-blindness forward, and regret that I have to condemn his test. This test is based on one of the most popular theories of colour-vision, and in practice results come out in many respects as Holmgren says they will. Let us consider it under the following heads :—

1. *Theory.* I have previously dealt with the objections to the Young-Helmholtz theory of colour-perception on which this test is based. In that chapter I have dealt with Holmgren's test in so far as it relates to the theory. It repeats all the errors of the theory upon which it is based.

2. *Material.* The material for the purposes of a colour-test is not a good one. First, we have the difficulty of obtaining correctly coloured wools ; then there is the great difficulty in obtaining duplicates of these wools. As I have shown in the chapter on the composition of colours

because two colours *look* alike it is not by any means necessary that they have the same composition. The probability is that if the dyes used are different the colours will differ in composition. As a matter of fact the sets of wools which are sold in this country bear a very feeble resemblance to Holmgren's true set.

When a good set of wools has been obtained, the colours are liable to fade; and this fading will take place more rapidly in the case of some colours than in others. This will prevent the results of examinations made with one set of wools from being uniform and comparable.

Then, the wools will become soiled, and this will happen in a very short time if the testing be conducted chiefly amongst the lower orders.

Then the greens which it is necessary to pick out will become more soiled than the others, and so afford a mark of distinction to the colour-blind, who, not being confused by the striking differences of colour, are able to notice minutiæ of this kind. It will be found, in testing a large number of persons, that those who are colour-blind will try to find some distinguishing mark in the wools selected by others.

There are other points connected with the material which enable the colour-blind to pass the test. Holmgren himself relates a case of a man who could distinguish between brown and green by the touch, but not by the colour.

The relative luminosity of the colours of wools is very great, and forms a distinguishing point to the colour-blind. An ordinary red-green colour-blind will not put a yellow wool with a green or red one, but he will put yellow glass with green or red glass.

3. *Method of Testing.* With regard to the method which is employed in this test, Holmgren says:—

"Theoretically our method most resembles those of Seebeck and Maxwell, as it is based upon a *comparison* between different colours. It therefore seeks to discover the chromatic perception of the subject, disregarding the *names* he gives to the colours, as generally it is not necessary he should designate the names."

It will be seen that one great difference between Holmgren's method, and mine in the use of the Classification Test, is that he says that the names given to the colours may be disregarded, whilst I am of opinion that a person cannot be efficiently tested if this be done.

The method of matching colours should, to be properly carried out, be one of mentally naming them, or else the test is useless on account of this point alone. For instance, if a man say to himself, "This test colour is green; therefore I must pick out all the colours having this hue of green in them," he will go through the test as it should be gone through; but if, on looking at the wool, he be influenced more by shade, he will put light blues, yellows, grays, and browns with the light green. This will be especially liable to happen in cases of the lesser degrees of colour-blindness, in which the green is simply enlarged and encroaches on the yellow and blue.

When using Holmgren's test in strict accordance with his instructions, I have examined normal-sighted persons who have put grays and browns with the test green. After a short lesson in colours, these persons were able to classify a large number of coloured objects correctly, and explained that the browns and grays were very like the test green in shade. Similarity, other than that defined by the word "colour," is the great source of error in this test, and it is exaggerated by ignoring colour names.

I am informed that applicants for situations on the railway who have failed with Holmgren's test, have gone

to a Berlin wool shop and been instructed by one of the saleswomen. After this they have again gone up for the test, and passed easily. Comment is unnecessary.

The question then comes up for consideration: What are the differences between matching and naming colours? When a person is asked to name a colour without being allowed to compare it with other colours, he has to compare the present impression of colour with those impressions already in his mind. In order, therefore, that he may be able to name colours, he must at least have an elementary knowledge of colour-names. A person who is required to match colours may be guided chiefly by colour or chiefly by shade; in fact, by similarity of any kind. A person who has been educated with regard to colour will be chiefly influenced by colour; but a man who has only an elementary knowledge of colours will be influenced considerably by shade. If we compare the two methods with persons belonging to the educated classes, we shall see how inferior the method of matching is to that of naming. Let us take a hundred and fifty wools, and examine two similarly colour-blind educated persons with them. The first is asked to classify the wools, putting all those of similar colour together, the second is asked to name the whole of the wools one by one. It will be found that the second person will make very much more numerous mistakes than the first. The reason of this is obvious: in the case of naming colours, the person has only the impression present in his mind to enable him to name a colour correctly; in the case of matching colours, he has other colours present with which he can compare the test. We all know what to do when we are doubtful what to call a colour—namely, compare it with some colour about which there is no doubt. Slight differences of colour become more marked on comparison.

It will be seen that the method of matching colours is really very inferior to that of naming them, if an equal number of colours be taken. Holmgren's comparison was hardly a fair one, as he compared his method, with a hundred and fifty colours, and that of naming with about six colours. The argument he uses about colour-ignorance is a fallacious one, because a candidate *ought* to know the names and qualities of the four principal colours—red, yellow, green, and blue. He has to name a light without comparison when at work. In my Classification Test I tried, by the introduction of different test colours and various materials, to get rid of the disadvantages of comparison, and partially succeeded. The test, however, is inferior to that with a lantern and neutral glasses.

4. *The Test Colours.* The test colours used are a light green and a light shade of rose. A red is also used as a confirmatory test.

A pure green is one of the worst possible colours to choose for a first test, because in the five, four, and three-unit the green is simply enlarged. Therefore, if the blue-greens be removed, these colour-blind persons may easily pass through the test without detection.

Reference to the chapter on the Classification of the Colour-blind will show how these theoretical expectations are verified. It will be noticed, both in the examination with my Pocket Test and in the Classification of Colours that fewer mistakes are made with a pure green than almost any other colour. In some cases only greens have been put with Holmgren's test green, whilst green has been put with my test red No. III.

The rose test, No. II. A, is a colour which is too red; a colour similar to that produced by mixing this colour with violet, is more valuable for a test colour. In many

cases of colour-blindness II. A will simply be put with reds.

Some of the features of this test are due to the use of impure colours. The red test skein (II. B) reflects a large quantity of violet light. This makes very little difference in testing an ordinary case of red-green blindness, because the preponderance of red rays causes the colour to fall into the red psycho-physical unit. But the presence of the violet rays causes the colour to be perceived as red mixed with a large amount of gray, because a mixture of violet and red appears gray to the two-unit. The green, therefore, that he matches with this colour will be a blue-green, containing similar proportions from each unit. The red III. in my Pocket Test is a much purer red, and the two-unit therefore match it with bright yellowish greens (78 and 94), instead of the dull greens represented by 10 and 12 in Holmgren's plate.

Then, if the red end of the spectrum be much shortened, the red test II. B will not be classed with reds, but with blues, as happened to me in one case. The reason of this is, that, as a considerable number of the red rays are not perceived, they have to be subtracted from the composition of the colour. The violet rays predominating cause the colour to fall into the violet psycho-physical unit.

5. *Efficiency.* Whom are we to reject by this test? If we reject all the (so-called) partially red and green blind, we shall reject many persons who are practically competent. If we only reject the (so-called) completely red or green blind, we shall allow many persons who are dangerously colour-blind to officiate as signalmen. The test is more theoretical than practical, the main object of testing for colour-blindness being apparently lost sight of; thus it has to be proved that a man who puts a con-

fusion-colour with a green wool cannot distinguish between a red and a green light. Then, when a man has put a confusion-colour with a green wool there is still the point to be decided whether he has been judging more by shade than by colour. To an uneducated man a light green and a greenish gray are very much alike. In my experience an ignorant four-unit colour-blind (that is, a person who is partially colour-blind, but not colour-blind to an extent necessitating his rejection) is more likely to fail than an edŭcated two-unit (red-green colour-blind).

A person with central scotoma will escape detection if examined by this test. For example, I examined a person with central scotoma with my Pocket Colour-test (in which small pieces of coloured material are ranged in rows), and found him perfectly colour-blind with regard to red, green, and gray. I then examined him with Holmgren's test, and he went through it, correctly, with the greatest ease. As a light, at a distance, occupies the central portion of the field of vision, these persons will be found to recognize colours when close to them, but not when they are at a distance.

The red end of the spectrum may be considerably shortened, so much so that a person may scarcely be able to distinguish red from black. It is obvious that this will not prevent him from matching a light green wool with other green wools.

It is not by any means an efficient test. We cannot reject by it those persons who would be dangerous as sailors or engine-drivers, and only those persons.

It is also possible to instruct a red-green colour-blind so as to enable him to pass through Holmgren's test with ease. I have taught an uneducated red-green colour-blind to pass this test with less than five minutes'

instruction. This man had previously put the ordinary confusion-colours with the test green, and painted a picture for me, representing the grass with vermilion, believing that he had made a very good match. After my instructions he picked out the correct colours with ease and certainty. It must not be supposed that these instructions were elaborate. I first told him to notice the *exact* colour of the test green, and, when picking out the colours, to be guided by colour only, and not in any degree by shade. Having picked out the correct colours, I showed him that they formed a series commencing at a very light green, and ending at a dark one. I told him, therefore, to avoid all colours of the same shade as the test green, and to note how many wools I had picked out. I then picked out a typical blue, yellow, and red, and placed them beside the test green. I then told him that he need only know four colours, red, yellow, green, and blue, and must pick out the exact hue of green, carefully avoiding all greens which inclined to yellow or blue.

It will be noticed that my instructions were not much more complicated than those recommended by Holmgren in order to help a stupid person. Holmgren says that it is an advantage for colour-blind persons to look on whilst the normal-sighted go through the test; and also, if necessary, the examiner should show the examinee how he is to proceed, picking out the correct colours himself first.

When the theory of psycho-physical perception is considered, it will be seen how it is possible for a red-green colour-blind to be instructed so as to pass through this test. Green and red are contained in approximate, not in absolute, psycho-physical units.

Many persons belonging to the class of the three-unit colour-blind will escape detection if examined with this

test, and this is more liable to occur if the blue-green wools be omitted, as Holmgren suggests, in the first test. They will rarely fail to pass if they be allowed to watch a number of other persons going through the test as in Holmgren's method of testing a number of persons, or if they have had any previous experience with the wools. I have met with many educated three-units who have succeeded in picking out the whole of the greens from a bundle of wools. The commonest mistake is that of putting blues in the pile of greens, and omitting one or two blue-greens.

Again, many colour-blind persons will pick out a large number of green wools at once, perhaps leaving one or two in the pile. An inexperienced examiner may pass the candidate. Should he not do so, he is placed in a difficult position if the candidate refuse to pick out any more wools, saying that there are no more like the test green. He has put no confusion-colours with the test. Holmgren suggests that under these circumstances the examiner should take one of the greens which has been overlooked, and one of the confusion-colours, and ask the candidate which two out of the three are most alike. I contend that this is not a fair way of examining, because the answer to the question so much depends upon the point of view from which the wools are regarded, namely, which is the examinee likely to be influenced by, the shade or the colour. Uneducated persons always find difficulty in matching shades of colour, and they will often answer, "Neither is much like the test." Under any circumstances an uneducated and unpractised colour-blind is under a disadvantage, compared with an individual who is educated and practised in colours.

3. Naming Colours.—A method of testing, in which the candidate is required to name a number of coloured

objects, would at first sight appear sufficient to show if he were colour-blind or not; but there are many objections to its use. To ask a person to name a number of coloured objects taken at random would be a very inefficient and uncertain method of testing. The candidate, though colour-blind, might name the colours correctly, and the reason of this I have shown in the last chapter. A three-unit would name any number of pure greens correctly if he named them in accordance with his ideas of colour. If the colours were chosen for the purpose, fairly accurate results might be obtained by this method of testing, but the procedure is tedious. If the examiner have to choose his own colours he will require to have a considerable knowledge of colour-blindness in order to choose those which are likely to be wrongly named. As the materials for testing may not always be at hand, I will give a few hints as to the selection of coloured objects, as I have several times had to decide if a person were colour-blind or not by this method. The first obvious principle in the selection of colours is to obtain those which appear one colour to the normal-sighted, and another to the colour-blind. The two-unit recognize yellow chiefly by its superior luminosity, and therefore find great difficulty in naming dull yellows correctly. Yellow-browns are, therefore, useful colours to ask the candidate to name. A yellow brick is a good example of this class of objects. Another class of objects which are very useful for the purpose of testing are cloths or silks, with a pattern of a certain colour worked on a ground of the same colour, but of a slightly darker or lighter shade. The normal-sighted will name the colour easily, but the colour-blind will find great difficulty. Materials which contain colours which are twin to the colour-blind are useful for testing, such, for instance, as

an antimacassar worked in terra-cotta and olive-green. Materials, in which the colours are of nearly equal luminosity as coloured glass, are very likely to be miscalled. A coal fire is a useful object for a test, the candidate being asked to name all the colours which he sees in the fire, and to point out where they are. Objects which are generally of a certain colour, when of that colour should be avoided, but when they are of another colour they may be used. Objects which are always of the same colour are useless for testing purposes. Objects which contain gradations of colour, as flowers, leaves with reddish veins, fruit, feathers, etc., are useful, the candidate being asked to point out the colours which he sees. Colours which in themselves present difficulty to the colour-blind, as oranges, violets, grays, browns and purples should be particularly used.

4. **Twin Colours.** — Cohn's worsted letters, Donder's discs, Stilling's plates, and Grossman's method are included under this head.

The method of employing twin colours is useless, because there are different degrees of colour-blindness. Thus, dealing only with the two-unit, we may have a spectrum of normal length, or the red or violet end may be shortened in a variable degree. If, for instance, we had twin letters of red and green made with colours selected by a two-unit with an unshortened spectrum, on examining a two-unit with considerable shortening of the red end of the spectrum we should find that he would read the letters with the greatest ease because the red portion (on account of a large number of rays not being perceived) would appear much darker than the green. In the same way, combinations which do not contain red are rendered useless by the presence of a neutral band, or shortening of the violet end of the spectrum. In addition, there are the

minor objections of the colours having different degrees of luminosity, arrangement of threads, etc.

Stilling's lithographed plates have the additional objection of having the twin colour overlapping the ground.

5. **Tests in which the Complementary Colour has a Part.**—Shadows coloured by contrast, Cohn's chromascioptieon, Waldstein's chromatoscope, and Phlüger's test come under this head.

Tests of this description have very little value; they are more likely to detect the ignorant than the colour-blind. The colour-sense is diminished in the colour-blind, but not to such a degree as to prevent them from seeing complementary colours.

6. **Quantitative Tests for Colour-blindness.**—In Chapter XI. I have discussed the methods of ascertaining quantitatively the degree of colour-blindness. It now remains for me to deal with those tests which have been contructed upon the theory that the various degrees of colour-blindness are only varying degrees of certain defects. In the case of the Young-Helmholtz theory, varying degrees of red-blindness, green-blindness, or violet-blindness. I have shown that there are several causes which go to make up the total defect which is evident as colour-blindness. Shortening of the red end of the spectrum interferes very considerably with the perception of red at a distance; but diminution in psycho-physical perception has comparatively little effect upon the perception of colours at a distance. I have several times examined persons belonging to the class of the three-unit with an unshortened spectrum, and found that they were able to recognize red and green at the normal distance. It seems to me that, until the various causes which give rise to defects of colour-perception are definitely recognized, no efficient quantitative tests can be constructed.

A test which has been devised for ascertaining a colour-defect of a certain kind—for instance, the perception of colours at a distance—will not show whether there are colour-defects of other kinds, as diminished psycho-physical perception.

APPENDIX

I MUST first say a few words about the report of the Colour-Vision Committee of the Royal Society.[1] It will be remembered that they recommended the wool test, and matching instead of naming. I should have thought that acting only on the evidence before them they would have come to an opposite conclusion. The last page of the committee's report gives a summary of the cases of colour-blindness detected at the examination of 300 railway employees. One is struck by two facts: first, that five colour-blind persons escaped detection by the wool test, and secondly, no colour-blind person escaped detection by all the lantern tests. That is to say, though a colour-blind person was passed by one lantern test, the same man was rejected by another examiner using another lantern test. The obvious conclusion is, therefore, that a lantern test could be (and I claimed had been) constructed that would detect all cases. In this connection I may mention that I am incorrectly reported as having passed No. 191, whereas I rejected him.

Opinion steadily changed until in 1903 the Ophthalmological Society appointed a Colour-Vision Committee to report on the alleged inefficiency of Holmgren's test. This committee brought out its report on January 24th, 1904.[2] I give this report in full as it was the first official confirmation of the facts which are of so much importance to those who have to test for colour-blindness.

[1] Proc. Royal Society, 1892.
[2] Trans. Ophth. Soc. 1904, p. 367

Preliminary Report of Colour-Vision Committee of the Ophthalmological Society.

'Your Committee have considered the subject referred to them, namely, the alleged inefficiency of Holmgren's test to detect certain cases of colour-blindness, and beg to report as follows :

'We agree, as the result of our own examinations, with the generally received opinion, that Holmgren's test, used with knowledge and care and in the spirit, but not necessarily according to the letter of the instructions, is sufficient for the detection of a large number of cases of colour-blindness for which it was devised, viz., those whose defect is of a kind that renders them liable to make mistakes in coloured signals ; and further, that the test gives, in a large number of cases, such an indication of the degree of defect as will justify the examiner in deciding from it alone, without other tests, whether a given colour-blind person is or is not unsafe, as a signal or look-out man.

'But we agree with Dr. Edridge-Green that some cases of colour-blindness cannot be detected by Holmgren's test, however skilfully and fully used ; and that others that satisfy Holmgren's first test (pale green) easily, and would therefore be passed as normal in most ordinary routine examinations, are exposed by a careful use of Holmgren's second test (Rose test-colour). We further agree with Dr. Edridge-Green that some at least of the cases just referred to, when tried with the signal lantern, make mistakes that at once disqualify them.

'The discovery of the defect in such cases can be made with certainty and, as a rule, easily, by a modification of the wool test, such as that of Dr. Edridge-Green, in which, as the result of his investigations, he recommends a series of colours different from Holmgren's.

Another kind of defective colour-vision, apparently not known to Holmgren, is that caused by shortening of one or other end of the spectrum, that is, inability to perceive some of the rays of lowest refrangibility at the red end, or of highest at the violet end.

Shortening of the violet end, when unaccompanied by any other defect of colour-vision, is practically important only when violet or purple signal lights are used.

Shortening of the red end is more important. It is usually combined with defective colour-difference perception, but even when it exists alone, it will, if it reaches a certain degree, render its subject

unsafe as a signal reader, by hindering the perception of red at a distance, or when viewed through a haze, which only allows the passage of the rays of low refrangibility.

Your committee believe that the above report answers in the strict sense the reference made to them, but they think that its value would be enhanced, if they could report more fully on the subject after having examined a larger number of colour-blind persons.

As the daylight in London, at this season, is short and uncertain, and as time is required to collect cases, they propose to postpone such fuller report for a few months.

(Signed), W. ADAMS FROST,
Chairman.

January 28th, 1904.

When the committee of the Royal Society recommended the Holmgren test, and that it was not necessary for a medical man to test for "vision" and "colour-vision," my connection with the Board of Trade ceased, my place being taken by a physicist, the secretary of the committee. Therefore, for this obviously medical duty the Board of Trade does not employ a single medical man. Since the adoption of the wool test there has been increasing dissatisfaction amongst the officers, chiefly on account of the large number of normal-sighted men who have been rejected. It will be seen in the Board of Trade report for last year that over fifty-three per cent. of those who were rejected by the wool test and appealed were found to be normal-sighted. I have lately made inquiries of the railway companies; some adopt an efficient method of testing, but on the whole there has not been much change. The Admiralty have lately asked my advice as to the colour tests to be used, and there is every hope that they will soon have an efficient method of testing. I have in the past examined several naval officers who have passed the Holmgren test, but failed with my lantern.

I have now brought out a new form of lantern, which is made by Meyrowitz, 1A Old Bond Street, W., who also makes my Classification Test, but all that I have said in this book applies equally to both forms.

Helmholtz in the second edition of his book stated that

the explanation given by him in the first edition is not sufficient to explain the facts of colour-blindness.

The psycho-physical theory is consistent with the theory of evolution. All the facts which can be obtained from the study of museums and literature point to the view that the sense of light was developed first, and then the sense of colour. Those waves which differ from each other most in refrangibility were first distinguished, namely, red and violet. In the course of evolution, we have passed through all the varieties of psycho-physical colour-blindness. It is obvious that if a certain portion of the visual centre be set apart for the perception of colour, when it was very small and ill-developed, it would only be able to perceive differences of considerable magnitude, but as more cells were added to this centre, greater and greater power of perceiving differences arose. Many facts show that the fovea and yellow spot are more effectively represented in the cortex cerebri than the peripheral parts of the retina. Very bright colours are, however, recognised by the periphery. Each nerve cell might at first have been connected with many nerve fibres, and the number gradually diminished as evolution proceeded. Then all the degrees of psycho-physical colour-blindness were passed through, until the present stage of the development of the colour sense was reached. These facts show that colour-blindness is only an example of an earlier state in the development of the colour-perceiving centre. It will be noticed that evolution gives an explanation of the apparent trichromatism of normal colour-vision. It is evident [1] that the majority of persons in the course of evolution saw the rainbow as consisting of three colours, red, green, and violet. As the colour sense became further developed, a new colour, yellow, was seen, and so a mixture of red and green could only give rise, in the normal-sighted, to a sensation of yellow, the colour which had replaced the red-green of an anterior state of development.

In Chapter V. I have expressed the view that the visual

[1] *Nineteenth Century*, April 1902.

purple is the visual substance, and that the cones were not sensitive to light but only to chemical changes in the visual purple when it had been diffused around them. I have now shown that this actually takes place. I have with Devereux Marshall examined the retinas of several monkeys after they had been kept in a dark room for forty-eight hours, and found that the visual purple was to be found in the yellow spot, but situated between and not in the cones. In fact, the visual purple appeared to be concentrated in the yellow spot, as this was the reddest part of the whole retina. The monkey has a retina similar to that of man, and so is admirably adapted for the purpose of the experiment.

There are a great many other facts which support the view which I have expressed with regard to the relative functions of the rods and cones of the retina. As the centre of the yellow spot, the fovea, is free from rods, we should expect that, if light fell upon this portion of the eye without also impinging upon a portion of the retina containing rods, the visual purple being used up and not replaced, we should find that light may fall upon the most sensitive part of the eye without producing any sensation. This is actually the case. A very simple experiment will convince the reader.

1. If we look at two isolated stars of equal magnitude, either may be made to disappear by looking fixedly at it whilst the other remains conspicuously visible. I found that the phenomenon was most marked on a dark night, and when the star looked at was in a portion of the sky comparatively free from other stars. When only one eye is used on a very dark night, a considerable number of small stars occupying the centre of the field of vision may be made to disappear whilst stars occupying other areas of the field of vision are plainly visible. 2. Other lights or objects when small and with dark surroundings, as, for instance, a piece of white cardboard on black velvet, may be made to disappear in a similar manner. 3. No change can be observed if a very bright light, a group of

stars, or a uniformly illuminated surface be made the object of the experiment. 4. If we look at an illuminated object through a pinhole in a piece of black cardboard surrounded by black velvet, we find that unless it be very bright it will not be visible at all. On moving the eye so that the image does not fall on the centre of the retina, the object appears brighter. When these experiments are made with a lantern the result is very startling. One moment we are looking at a bright light and the next have the sensation of having become quite blind, the sensation of absolute blackness being greater than can be obtained in any other way. Just before the light disappears it seems to pulsate, appearing and disappearing as if a rose diaphragm were shut and opened before it, except that the reappearance of the light is always from without, inwards. The same appearance may be seen with the stars on a dark night. I have made a great number of experiments in order to find out which colour disappears first, but these experiments require special apparatus. The chief essentials in making a bright light disappear are to use only one eye and to have the surroundings of the light absolutely dark. In my experiments, which I make at night, I use a specially constructed lantern arranged so that all extraneous light can be as far as possible excluded. The practical importance of these experiments is obvious, as a sailor on looking at what he first thought was a light and seeing nothing there might think he was mistaken, and so an accident might arise. These facts ought to be generally known to seafaring men.

It is not generally known, though Helmholtz mentions the fact and also states that it is quite inexplicable, that a perceptible interval elapses before we are able to see with the yellow spot. When once the fact has been noted it is very easy to see the phenomenon in almost any circumstances; but in order to see it best one eye should be used, and the surface looked at should not be too brightly illuminated. On opening the eye quickly, the portion of the field of vision corresponding to the macula will be seen as an oval black

spot, and light will appear to invade it from without, inwards, the fovea centralis being the last point to convey a sensation of light. This experiment demonstrates the diffusion into the yellow spot of the visual substance. It may also be noted that on shutting the eyes, vision is most persistent at the fovea centralis, just as we should theoretically expect, as it would take longer for the visual purple in the fovea to be used up in the absence of light.

I have made many experiments with a perimeter in order to ascertain at which point of the retina a piece of paper covered with luminous paint appeared brightest. I found that it made an oval figure, the smaller diameter of which occupied the vertical direction and was 10° on either side of the point of fixation. The long diameter was in a horizontal direction and occupied a position from 15° to 20° on either side of the point of fixation.

There are many other phenomena connected with the yellow spot and which equally support the theory. For instance, under intermittent light the yellow spot appears as a black patch with a purple substance moving rapidly towards it from adjacent parts. If we look at a bright light reflected from metal so that there is darkness on one side and light on the other, on the light side there appear to be innumerable little purple rivers which seem to be moving rapidly towards the central spot. The purple appears to move in minute spots, and the space between them appears green.

If in a dimly lighted room we shut our eyes and then look as if at a distant object, concentric purple circles appear, contracting and rolling inwards towards the centre of the field of vision. As each wave reaches the centre it becomes brightly luminous and then breaks up and disappears.

A positive after-image of a purple colour can be obtained after white light or any spectral colour.

Von Tschermak, Hering, Hess, Garten, and others, have found only gradual quantitative differences in the sight between the foveal and extrafoveal area. The phenomenon of Purkinje, the alteration of optical white equations by the

state of light-and dark-adaptation, the colourless interval for spectral lights of increasing intensity, the different phases of the after-image—all these subjective reactions exist, not only in the extrafoveal, but also (only gradually diminished) in the foveal region.

Burch has made some successive contrast experiments. He calls them artificial temporary colour-blindness, but this is a misnomer, as the results bear no relation to ordinary colour-blindness. He states that light from D (sodium light) will fatigue the eye for both red and green. It occurred to me that as these experiments had been made with very bright lights, and yellow was such a luminous colour, the apparent weakening of the red and green was a luminosity contrast effect similar to that experienced on looking at a feeble light after viewing a bright one.

Devereux Marshall and I have made some experiments on tiring the eyes with burning sodium, which gives out a monochromatic, orange-yellow light. We found that the yellow disappeared entirely from the spectrum. The red and green were scarcely affected—in fact, not as much as the blue, which could be hardly recognised as a colour. The red was not in the least shortened, and it and the green appeared to be free from any yellow element. The orange appeared as red, and the red and green met without the least appearance of yellow.

When the eye is fatigued with red light, even for a short time, there appears a considerable shortening of the red end of the spectrum.

The transforming apparatus in the eye formed by the rods and cones obviates all the difficulties raised by physicists and which made them consider it necessary to limit the number of colour sensations.

Gotch has written some very interesting papers on the electrical changes in a frog's retina caused by light. He finds that a similar electrical change is produced by light of all wave lengths but that there is a difference of degree. He finds evidence of three definite changes in the retina

caused by light. I consider that these three processes correspond to the following conditions: the first, which appears to be a short interval, to the diffusion of the visual purple into the surrounding retina, the second to the decomposition of the visual purple by light, and the third to the stimulation of the ends of the cones by the products of the decomposition.

Waller[1] also finds that coloured lights act in the same direction, and in accordance with their luminosity. No electrical evidence is obtained of antagonistic influence.

The view that the visual purple is the essential factor in vision, in addition to explaining the facts, brings them into relation with other facts of physics and chemistry on the one hand and with general opthalmology on the other. We know that the visual purple gives a curve which is very similar to that of many other photochemical substances. We know that with photochemical substances the chemical effect is not proportional to the intensity of the light—that is, a different curve is obtained with weak light to that which is formed with light of greater intensity. It is reasonable therefore to expect that the visual purple, which is formed by the pigment cells under the influence of a bright light, will be somewhat different in character to that which is formed in darkness. Again, from the chemical analogy which I have just given, even if the visual purple were of the same character we should not expect similar curves with different intensities of light. It is probable that both factors are in operation. This deduction at once gives an explanation of the Purkinje phenomenon, or the fact that when the eye is adapted to darkness the point of greatest luminosity is shifted more towards the violet end of the spectrum.

We also have an explanation of other conditions—such as erythropsia or red vision, white objects appearing more or less red. If we suppose that the eye has remained in a state of light adaptation, the visual purple produced being more sensitive to the red rays, objects appear of this colour. As

[1] Phil. Trans., 1900, p. 136.

we should expect, erythropsia is frequently associated with hemeralopia, or difficulty in seeing in the twilight, the eyes being adapted to light and not to darkness. In green vision the eyes have probably remained in a condition of more or less adaptation to darkness, and are therefore more sensitive to the green rays.

In total colour-blindness the mechanism for adaptation to light is probably defective, and this would account for all the symptoms.

Some curious facts follow from this hypothesis—for instance, the after image of black should be green not white, and this is the case, as the reader can easily ascertain for himself, by looking at a black object and then at a white one, as at the snow. This fact gives an explanation of a pretty little toy, which excited much interest a few years ago, Benham's top. This consists of two sectors, one white and one black, on the white sector are black lines at intervals and at different distances from the centre. When the top is turned the black lines nearest the black disc appear red, this red being the contrast colour to the green which is seen as the after image of the black disc. Further details are given in my letters in the *Ophthalmoscope*, April and June 1909.

The following three curves almost correspond :—

1. The luminosity curve for the threshold of stimulation.
2. The stimulation value for total colour-blindness.
3. The absorption curve of the visual purple.

We also find that the curve obtained when the eye is partially adapted to light corresponds to the curve obtained with persons having shortening of the red end of the spectrum, so that we have only to assume that the receiving apparatus is less sensible to stimuli in some persons than in others to obtain an explanation, and we know that this exists with other sensations.

I have shown that no reduction theory of colour-blindness can explain the facts :[1] by reduction theory I mean a theory

[1] *Colour Systems.*—Trans. Ophth. Soc. 1906.
Observations with Raleigh's Apparatus.—Trans. Ophth. Soc. 1907.

which assumes that some light and colour-perceiving substance is absent. There are many dichromics who when asked to match red, yellow, and green will make a match with the spectral colours which as far as shade is concerned is a match to the normal-sighted. I showed a dichromic to Professor v. Kries and he admitted that it was not a reduction form.

I have marked out in wave-lengths the size of the various portions of the spectrum which appear monochromatic to different classes of persons.[1] It will be seen that the theory of psycho-physical perception is borne out in the minutest particular.

The following are the monochromatic patches, marked out for myself in Ångstrom units, with a very bright spectrum. It appears as if the patches bore a simple numerical relation to the whole spectrum; for instance, the red, violet, and largest green patch are respectively one-fifth, one-seventh, and one-ninth of the spectrum. I hope to find a numerical relation between the patches of persons possessing different degrees of colour-perception and between them and the normal.

1 2 3 4 5 6 7 8
6909 – 6338 – 6180 – 6105 – 6028 – 5964 – 5907 – 5850 –
571 158 75 77 64 57 57 43

9 10 11 12 13 14 15 16
5797 – 5743 – 5678 – 5566 – 5344 – 5126 – 5022 – 4964 –
54 65 112 322 218 104 58 61

17 18 19 20 21 22
4903 – 4848 – 4789 – 4719 – 4633 – 4478 – 4058
55 59 80 86 155 420

I will conclude by a short recapitulation of the whole theory. A ray of light impinging on the retina liberates the visual purple from the rods and a photograph is formed. The rods are concerned only with the formation and dis-

[1] *Observations on hue perception.* Trans. Ophth. Soc. 1907.

tribution of the visual purple, not with the conveyance of light impulses to the brain. There are cases in which the visual purple is differently constituted and is not sensitive to certain rays at one or both ends of the spectrum. The decomposition of the visual purple by light chemically stimulates the ends of the cones (very probably through the electricity which is produced), and a visual impulse is set up which is conveyed through the optic nerve fibres to the brain. If it were possible, in a case in which the spectrum appeared of similar length and brightness to both, for a normal-sighted person and a colour-blind one to exchange eyes, the normal-sighted would still see colours properly and the colour-blind would still be colour-blind. The character of the impulse set up differs according to the wave-length of the light causing it. Therefore in the impulse itself we have the physiological basis of light, and in the quality of the impulse the physiological basis of colour. The impulse being conveyed along the optic nerve to the brain, stimulates the visual centre, causing a sensation of light, and then passing on to the colour-perceiving centre, causes a sensation of colour. But though the impulses vary in character according to the wave-length of the light causing them, the colour-perceiving centre is not able to discriminate between the character of adjacent impulses, the nerve cells not being sufficiently developed for the purpose. At most, seven distinct colours are seen, whilst others see in proportion to the development of their colour-perceiving centres, only six, five, four, three, two, or one. This causes colour-blindness, the person seeing only two or three colours instead of the normal six, putting colours together as alike which are seen by the normal-sighted to be different. In the degree of colour-blindness just preceding total, only the colours at the extremes of the spectrum are recognised as different, the remainder of the spectrum appearing grey.

INDEX.

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D8